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# A dose of nature: Two three-level meta-analyses of the beneficial effects of exposure to nature on children's self-regulation<sup>☆</sup>

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## ABSTRACT

There is growing evidence that exposure to nature, as opposed to a built environment, is associated with better health. Specifically in children, more exposure to nature seems to be associated with better cognitive, affective, and behavioral self-regulation. Because studies are scattered over different scientific disciplines, it is difficult to create a coherent overview of empirical findings. We therefore conducted two meta-analyses on the effect of exposure to nature on self-regulation of schoolchildren ( $M_{\text{age}} = 7.84$  years;  $SD = 2.46$ ). Our 3-level meta-analyses showed small, but significant positive overall associations of nature with self-regulation in both correlational (15 studies,  $r = .10$ ;  $p < .001$ ) and (quasi-) experimental (16 studies,  $d = .15$ ;  $p < .01$ ) studies. Moderation analyses revealed no differential associations based on most sample or study characteristics. However, in correlational studies the type of instrument used to measure exposure to nature (index score of nature vs. parent-reported exposure) significantly moderated the association between nature and self-regulation. Stronger associations were found when exposure to nature was assessed via parent-reports than via an index such as by a normalized difference vegetation index (NDVI). Our findings suggest that nature may be a promising tool in stimulating children's self-regulation, and possibly preventing child psychopathology. However, our overview also shows that we are in need of more rigorous experimental studies, using theoretically based conceptualizations of nature, and validated measures of nature and its putative outcomes.

## 1. Introduction

In the near future, almost 70% of children worldwide will grow up in cities (Unicef, 2016). We know relatively little about the possible risks of growing up in urban versus less urban environments. For example, children in urban environments may have fewer opportunities to engage in outside play activities and to spend time in natural, green area's (Kellert, 2002, 2005). Indeed, characteristics of children's residential neighborhood, such as the amount of traffic and open, green spaces, are associated with behavior, such as outdoor play and physical activity, that facilitate their development (for a review see Christian et al., 2015). The possible role of the physical environment in child

development has received far less attention than other environmental factors, such as parenting or education. However, a growing body of literature suggests that exposure to environments that are high on natural features such as water, grass, and trees (as opposed to urban or built environments, predominantly consisting of streets and buildings), is related to better mental health outcomes in general, and better development of self-regulation in particular (for overviews, see Annerstedt & Währborg, 2011; Gill, 2014; Hartig, Mitchell, De Vries, & Frumkin, 2014; Markevych et al., 2014; Tillmann, Tobin, Avison, & Gilliland, 2018).

Specifically for children in primary school (or level 1 of the international standard classification of education: aged 4-12 years),

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spending time in natural environments may have important benefits (e.g., Faber-Taylor & Kuo, 2009; Gill, 2014; Jenkin, Frampton, White, & Pahl, 2018). These children face major developmental tasks in terms of self-regulation, or the exertion of control over the self by the self (McClelland, Ponitz, Messersmith, & Tominey, 2010). For example, focusing on your schoolwork while ignoring what is happening in the background and ignoring your inner distractions, learning how to regulate your emotions, and resisting temptations or delay gratification, all require self-control. The social cognitive theory of human behavior states that behavior is extensively motivated and regulated by the ongoing exercise of self-influence (Bandura, 1986). This social cognitive perspective differs from earlier work on self-regulation in that it does not define self-regulation as a singular trait but as a multi-dimensional and context-specific process entailing cognitive, affective and behavioral dimensions (Zimmerman, 2000).

Self-regulation operates through an interaction of personal, behavioral, and environmental processes (Bandura, 1986) and has been hypothesized to be a limited, consumable resource (Muraven & Baumeister, 2000; Baumeister, Bratslavsky, & Muraven, 2018). For example, coping with stress, regulating negative affect, and attentional focus, all require self-regulation. After using self-regulation for these purposes, the available amount may be reduced, and subsequent attempts at self-regulation may be more likely to fail (Muraven & Baumeister, 2000). This may increase the risk for inattention, negative affect, irritability, and non-compliance, which are behavioral manifestations associated with child psychopathology, such as Attention Deficit and Hyperactivity Disorder (ADHD) and Oppositional Defiant Disorder (ODD) (e.g., Campbell, Shaw, & Gilliom, 2000; Caspi, Henry, McGee, Moffitt, & Silva, 1995; Compas et al., 2017). At an early age, such behavioral manifestations predict socio-emotional functioning across the life-span (Jokela, Ferrie, & Kivimäki, 2009; Von Stumm et al., 2011).

Individual differences in self-regulation capacities are mostly explained by biological, familial and school factors (e.g., Blair & Raver, 2015; Bridgett, Burt, Edwards, & Deater-Deckard, 2015). The role of children's physical, and specifically the *natural*, environment in self-regulation is less well understood (see also Evans, 2006). However, different theories emphasize that nature is an important aspect of the quality of our environment and propose mechanisms through which as dose of nature may positively affect cognitive, affective, and behavioral dimensions of self-regulation (Kahn, 1997; Kellert, 2002, 2005; Markevych et al., 2017; Wilson, 1984). These theories may be classified in three general domains, namely theories on possible promotive (i.e., direct positive or instoration effect), protective (i.e., indirect effect via reduced harm or mitigation) and restorative pathways in which nature may contribute to self-regulation (see Markevych et al., 2017).

First of all, green spaces may promote self-regulation by increasing children's opportunities to play outside, which has positive effects on exposure to daylight and physical activity (Christian et al., 2015). Indeed, children show increased physical activity in green versus paved playgrounds (Raney, Hendry, & Yee, 2019). In turn, both natural daylight and physical activity relate to better mental health, and specifically to better affective and cognitive self-regulation (see for overviews Beute & De Kort, 2014; Piepmeyer et al., 2015). Moreover, such positive emotions associated with spending time in a natural environment might *broaden* children's mindset by sparking the urge to play, explore, and promote novel, creative ideas and social bonds, which in turn further *builds* children's self-regulatory resources (i.e., the broaden-and-build theory, see Fredrickson, 2004).

Second, characteristics of a natural environment may protect against risk factors associated with a built or urban environment such as pollution, noise, crowding, and bad odors. These environmental factors have been shown to decrease self-regulatory capacities (see for an overview Muraven & Baumeister, 2000). For example, functional magnetic resonance imaging (i.e., fMRI) research showed increased brain responses during a working memory task when noise was increased, suggesting that brain function requires additional attention

resources under noisier conditions (Tomasi, Caparelli, Chang, & Ernst, 2005). Nature may reduce the impact of these risk factors through a natural buffer for noise and pollution via canopy and through providing recreational areas away from the crowds (e.g., Klingberg, Broberg, Strandberg, Thorsson, & Pleijel, 2017; Markevych et al., 2019).

Third, natural environments might have restorative qualities. According to the Attention Restoration Theory (ART, Kaplan, 1995; Kaplan & Kaplan, 1989), nature supports the replenishment of depleted resources, especially those related to cognitive self-regulation (Kaplan & Berman, 2010). Nature helps children recuperate from the informational load experienced in everyday life. The theory centers on fascination and claims that natural environments are inherently fascinating and draw attention without requiring effort. Nature may help replenish depleted attention through fascination or bottom-up attention. Moreover, ART proposes that nature may help forget daily hassles (being away), invites exploration (extent), and does not intervene with behavioral intentions (compatibility). Indeed, it was found that images of natural scenes were viewed longer and were rated as more restorative than images of built scenes. This effect was partly explained by a greater perceived complexity of the natural scenes (possibly related to patterns found in nature) (Van den Berg, Joye, & Koole, 2016). The Stress Recovery Theory (SRT; Ulrich, 1981, 1983; Ulrich et al., 1991) argues that nature supports the restoration of both affective and physiological detriments caused by stress. This theory builds on psycho-evolutionary theories on nature that propose we have a preference for unthreatening natural environments (also known as biophilia, Kellert & Wilson, 1995). Spending time in evolutionary-based preferred environments helps us recovery from stress and improves our mood. Indeed, adults reported, for example, serenity, space, and specifically refuge, as qualities of urban green spaces that they associate with less stress (Grahn & Stigsdotter, 2010).

### 1.1. Previous research

Although there is growing empirical support for theories on possible beneficial effects of nature, studies are scattered across different scientific disciplines (e.g., clinical or environmental psychology, education, and public health), resulting in a great diversity in conceptualizations of nature and mental health outcomes. This makes it more difficult to create a clear overview of findings. For example, in environmental psychology nature might be conceptualized as a percentage retrieved from general land-use databases or satellite images (i.e., Normalized Difference Vegetation Index) (e.g., Amoly et al., 2014), whereas in public health it may refer to physical exercise undertaken in green areas (e.g., Reed et al., 2013).

Nevertheless, many of these studies focus on outcomes related to self-regulation. Studies have assessed the effects of nature on cognitive aspects of self-regulation, such as children's ability to inhibit their dominant response (e.g., with the go-no-go test or the STROOP Color-Word test, Dyer, 1973) or attention span (e.g., with the Digit span backwards, Wechsler, 1995). For example, a cross-sectional study found that girls' (not boys') attention (summary measure based on e.g., Symbol Digit Modalities and Digit Span Backwards) and inhibition (a summary measure based on e.g., Matching Familiar Figure and, STROOP Color-Word Test) performances were positively related to the naturalness of the view from their home (Faber-Taylor, Kuo, & Sullivan, 2002).

Studies have also assessed affective aspects of self-regulation by assessing how exposure to nature is related to mood, experienced quality of life, or self-esteem (e.g., with the mood adjective checklist or the Rosenberg Self-esteem Scale, Rosenberg, 1965). For example, a cross-sectional study found that children ( $N = 287$ ) who reported to generally spend more time in urban greenspaces also reported better emotional wellbeing (measured with the Kid-KINDL, McCracken, Allen, & Gow, 2016). Furthermore, using screening instruments for attention, emotional, and behavioral difficulties such as the Strengths and

Difficulties Questionnaire (SDQ, Goodman, 1997), studies found associations between nature and behavioral manifestations of self-regulation. For example, the percentage of green space in a standard small area around the participants' homes ( $N = 6384$ ) predicted parent-reported emotional and behavioral self-regulatory problems over time in children aged three to five years (measured with the SDQ, Flouri, Midouhas, & Joshi, 2014).

An important limitation of most of the available literature is that most studies use correlational designs. Although many studies control for some confounders in their analyses, such as age, gender, socioeconomic status (SES), and area deprivation, these studies cannot completely rule out alternative explanations for the relation between exposure to nature and developmental outcomes. This is important since exposure to nature is not random but confounded with risk factors known to contribute to self-regulation, such as neighborhood quality, school quality, urbanization/population density, air quality, and physical activity (e.g., Almanza, Jerrett, Dunton, Seto, & Pentz, 2012; Evans, 2006; Schüle, Gabriel, & Bolte, 2017).

Studies in which participants who are exposed to nature are compared with participants who are not therefore have additional value. There are several studies on the beneficial effects of nature using pre-post or (quasi-)experimental designs. For example, studies in which nature is used in educational settings or is conceptualized as a working mechanism in therapeutic interventions, such as forest schools, physical activity in the presence of nature (i.e., green exercise), therapy using gardening and plant-based activities (i.e., horticulture therapy), and outdoor adventure programs (for overviews see Annerstedt & Währborg, 2011; Barton & Pretty, 2010; Santostefano, 2013; Williams-Siegfriedsen, 2017; Wilson & Lipsey, 2000). In adolescents and adults these interventions seem to be effective in increasing self-regulation (e.g., Barton & Pretty, 2010; Gustafsson, Szczepanski, Nelson, & Gustafsson, 2012; Wilson & Lipsey, 2000). However, in children these effects are inconsistent. For example, cycling whilst viewing a nature video lead to lower blood pressure, but not better mood, compared to cycling with no visual stimulus (Duncan et al., 2014). Also, green-based exercise did not lead to a larger increase in self-esteem compared to exercising in an urban environment condition (Reed et al., 2013).

However, in all these programs and interventions nature is only one of many elements, which makes it difficult to decompose the unique effects of nature on self-regulation (i.e., an omnibus effect). Pioneering experimental studies, in which participants are randomly assigned to different, relatively brief and focused, environmental manipulations, provide us with a more precise test of possible beneficial effects of nature. For example, children with an ADHD diagnosis seem to be better able to concentrate after a walk in a park (measured by the Digit Span Backwards, results with the Stroop Color-Word Test, Symbol Digit Modalities, and the Vigilance Task of the Gordon Diagnostic System Model were not reported), compared to a walk downtown or in a neighborhood (Cohen's  $d = .77$ ; Faber-Taylor & Kuo, 2009). The effects of a walk in nature on attention were partly replicated in a later study in a general sample: a walk in the park, relative to a walk in an urban setting, improved children's attention (using the Go/no go task, but no significant effects were found using the Digit Span Backwards) (Schutte, Torquati, & Beattie, 2017).

## 1.2. The current study

Although many studies on the possible beneficial effects of nature show promising results, we need a comprehensive overview of the current evidence before we can infer societal or clinical implications. To date, systematic reviews have mostly focused on adult populations and/or focused on specific types of nature exposure such as outdoor adventure/wilderness programs (Cason & Gillis, 1994; Wilson & Lipsey, 2000) or green exercise (Barton & Pretty, 2010). These findings cannot be generalized to nature in general or to children. Also, most reviews include a broad range of mental health outcomes, which makes it hard

to compare findings and conclude on the specificity of the effects of nature. Moreover, no meta-analytical overviews on outcomes in children are available. A meta-analysis (i.e., a statistical method of combining evidence) has several important qualities, amongst which more precise and accurate estimation of effects (compared to individual studies), and complements narrative reviews by enabling statistical assessment of sources of heterogeneity in effects (i.e., moderation) and investigation of publication bias. The current study presents two separate meta-analyses on correlational and (quasi-)experimental studies on the effect of exposure to nature on children's (cognitive, affective and behavioral) self-regulation.

## 2. Methods

### 2.1. Eligibility criteria

Studies were included if they (1) examined the association between exposure to nature and cognitive and affective self-regulation, or behavioral manifestations (e.g., emotional wellbeing, inhibition, attention, and ADHD); (2) included school children (aged 4-12 years and/or the sample or subsample mean age was under 12 years); (3) used quantitative data (qualitative studies or single-subject designs were excluded); (4) were published in peer-reviewed journals (e.g., conference abstracts, dissertations, and policy documents were excluded), and (5) were written in English. We only included data from published peer reviewed studies because even the most comprehensive searches are likely to miss unpublished data. If a complete sample of unpublished material cannot be obtained, inclusion of this data seems futile. Also, although unpublished data is not necessarily of less scientific rigor, it may be difficult to assess validity due to lack of reporting on the procedures and methods (see Cook et al., 1993). It has been argued that not including unpublished data might lead to an over-estimation of effects (i.e., file drawer effect). However, a current study among 187 meta-analyses found that this may actually only be the case in a minority of meta-analyses (Schmucker et al., 2017). Moreover, in psychology meta-analyses that included unpublished studies were more likely to show bias than those that did not (Ferguson & Brannick, 2012). In the current study publication bias will be assessed via funnel plot inspections and trim-and-fill procedures (Duval & Tweedie, 2000). We only included English manuscript so that all our sources are accessible for the international scientific community and our results can be replicated.

### 2.2. Search strategy

We searched the electronic databases PsycINFO (Ovid), ERIC (Ovid), Web of Science, and MEDLINE (Ovid) and Google scholar. The final search was completed on April 24th, 2019. Search strings were created by combining search terms for (1) exposure to nature, (2) self-regulation, and (3) age. No limit was set on year of publication. See Appendix A for the search syntax. The systematic search yielded 5333 records. Refworks was used to organize the data and duplicate files were removed. In addition, the reference lists of 31 review articles on exposure to nature, and were screened for titles (Appendix B). This additional search resulted in 41 additional articles.

After titles were screened, abstracts were read to further exclude non eligible studies. Next, the full text of 343 manuscripts were screened, which eventually led to the inclusion of 49 studies for the two meta-analyses combined (see list in Appendix C). In case information was missing, the corresponding author of the specific study was contacted with a request for additional information. If after two reminders we received no additional data, studies were excluded from the analyses. Fifteen were eventually included in the meta-analysis on correlational studies, with 15 independent samples, and 61 effect sizes. Sixteen studies were included in the meta-analysis of (quasi-)experimental studies, with 17 independent samples, and 45 effect sizes. See



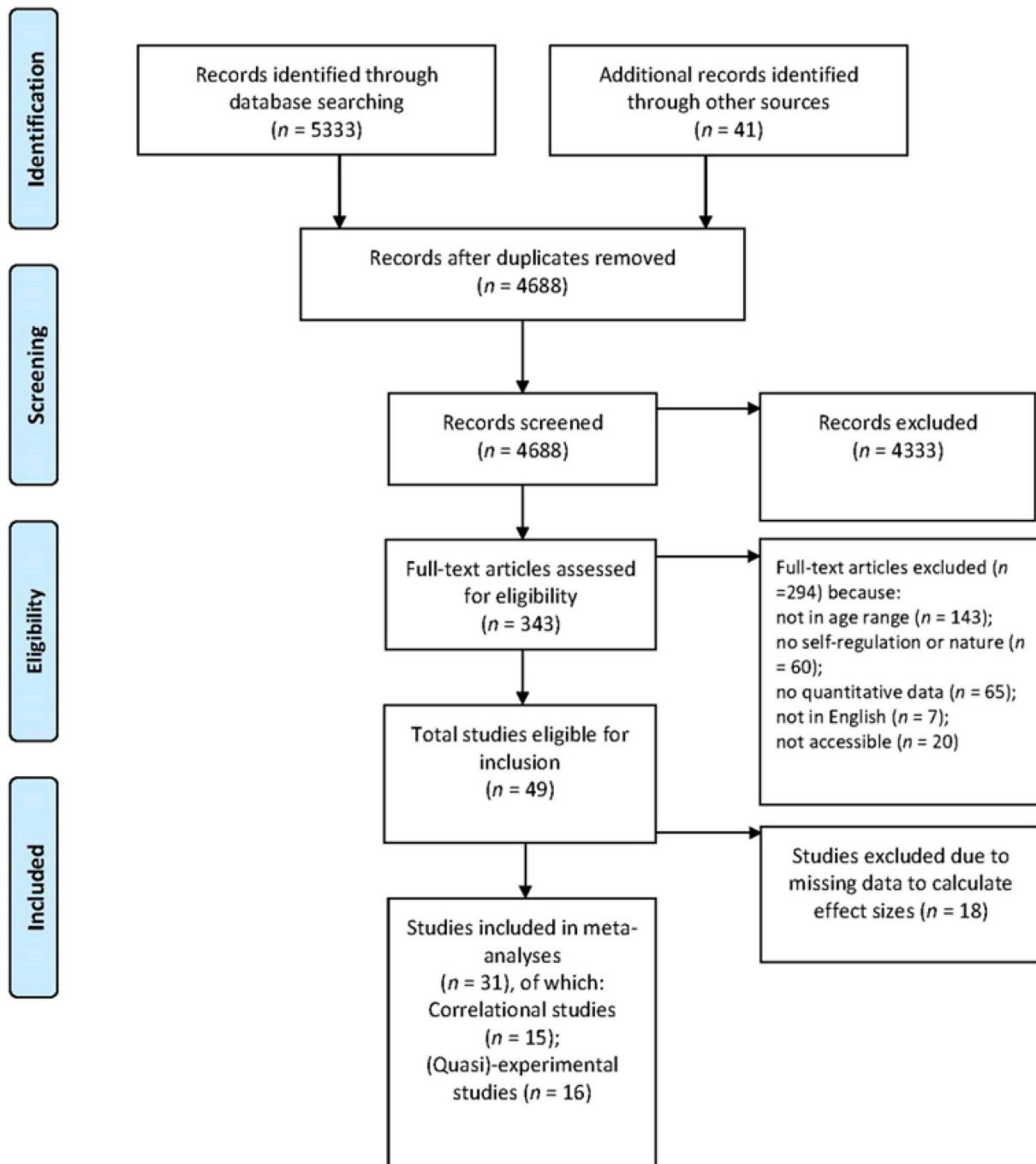


Fig. 1. Flow diagram.

Fig. 1 for the flow chart of our study selection process. This meta-analysis was registered in PROSPERO (registration number CRD42016045316), and the PRISMA-P guidelines for systematic reviews and meta-analyses were followed (Shamseer et al., 2015).

### 2.3. Coding procedure

All included studies were coded following the guidelines of Lipsey and Wilson (2001). The coding scheme was designed and discussed by the first three authors and coding was done by the both first authors. Characteristics of all coded studies are presented in Table 1 for correlational studies and Table 2 for (quasi)-experimental studies (full references can be found in Appendix C). The studies with an asterisk were initially included based on our search and screening, but excluded from

the analyses because of missing data (13 correlational studies and 5 experimental studies).

**Effect sizes.** In the correlational meta-analysis, effect sizes were expressed in correlation coefficients (Pearson's  $r$ ). Positive  $r$  values indicated a positive relation between self-regulation and the amount of exposure to nature (i.e., more nature is related to better self-regulation). When results were reported for separate non-informative groups (e.g., lower and higher age groups or school classes), we weighted the reported effect sizes on the basis of subgroup sample size and calculated effect sizes only for the whole sample. If papers only reported beta coefficients, we transformed these coefficients into correlations with the formula  $r = \beta + .05\lambda$ , where  $\lambda$  is an indicator equaling one when  $\beta$  is nonnegative and zero when  $\beta$  is negative (Peterson & Brown, 2005). We tested whether the Pearson's  $r$  that were transformed using the

**Table 1**  
Study Characteristics of Included Correlational Studies.

Author(s) (Year) <sup>b</sup>	N	Sex %boys	Age <sub>range</sub> in years (M <sub>age</sub> )	Eth.	Type sample	Country	Type nature/measure for nature	Informant/ Instrument nature	Instrument outcome	Informant outcome	Design	Self-regulation
* Amoly et al. (2014)	2623	50%	7–10 (8.5)	10%	General	Spain	Residential greenness/Time spent in green areas	PR/Index	Strengths and Difficulties Questionnaire (SDQ) + symptoms ADHD-DSM-IV	PR	Cross	Affective/Behavioral/Cognitive
* Bagot, Allen, & Toukhsati (2015)	550	46%	8–11 (9.7)	–	General	Australia	Residential greenness/Proximity green space	Index	Positive and Negative Affect Scale for Children (PANAS-C)	SR	Cross	Cross Affective
Balseviciene et al. (2014)	1468	49%	4–6 (4.7)	–	General	Lithuania	Residential greenness/Proximity green space	Index	Questionnaire (SDQ)	PR	Cross	Affective/Behavioral
* Chiumento et al. (2018)	24	41.6	9–11 <sup>a</sup>	–	Clinical	UK	Horticulture intervention	–	Wellbeing check cards	SR	Pre-post	Affective
* Dadvand et al. (2015)	2623	50%	7–10 (8.5)	–	General	Spain	Residential greenness/Proximity green space	Index	n-back test + Attentional Network Test (ANT)	Task	Long	Cognitive
* Dadvand et al., (2017)	1527	52%	–	–	General	Spain	Residential greenness	Index	Connors' Kiddie Continuous Performance Test (K-CPT)/Attentional Network Task (ANT)	Task	Long	Cognitive
Faber-Taylor & Kuo (2011)	421	80%	5–12 (8.5) <sup>a</sup>	–	Clinical	USA	Time spent in green areas	PR	one-item ADHD/ADD severity	PR	Cross	Cognitive/Behavioral
* Faber-Taylor, Kuo & Sullivan (2001)	96	75%	7–12 (9.4)	–	Clinical	USA	Time spent in green areas	PR	four-items on ADHD severity	PR	Cross	Cognitive/Behavioral
Faber-Taylor et al. (2002)	169	54%	7–12 (9.6)	100%	General	USA	Greenness from the window view	PR	Delay of Gratification/Digit Span Backwards/STROOP color-word	Task	Cross	Cognitive
Feng & Astell-Burt (2017a)	4968	51%	4–5 (4.5)	4%	General	Australia	Residential greenness/Proximity green space	Index	Questionnaire (SDQ)	PR	Long	Affective/Behavioral/Cognitive
Flouri et al. (2014)	6194	50%	3–7 (5.1)	74%	General	UK	Residential greenness/Proximity green space	PR/Index	Strengths and Difficulties Questionnaire (SDQ)	PR	Long	Affective/Behavioral
Kim, Lee, & Sohn (2016)	92	38%	9–11 (9.7)	80%	At-risk	USA	Residential greenness/Proximity green space	PR/Index	Pediatric Quality of Life Inventory	SR/PR	Cross	Affective
* Kuo & Faber-Taylor (2004)	452	79%	5–18 <sup>a</sup>	–	Clinical	USA	Time spent in green areas	PR	four-items on ADHD severity	PR	Cross	Cognitive/Behavioral
Madzia et al., (2019)	762	55%	7–12	21%	General	USA	Residential greenness	Index	Behavioral Assessment System for Children (BASC-2)	PR	Long	Long
* McEachan et al., (2018)	2594	–	(4.5)	71%	At risk	UK	Residential greenness	Index	Questionnaire (SDQ) Questions on emotions	PR	Long	Affective/Behavioral/Cognitive
* Markevych et al. (2019)	66823	51	10–14	–	General	Germany	Residential greenness	Index	International Classification of Diseases (ICD-10-GM)	C	Long	Cognitive/Behavior
Markevych et al. (2014)	1932	51%	9–11 (10.1)	–	General	Germany	Residential greenness/Proximity green space	Index	Strengths and Difficulties Questionnaire (SDQ)	PR	Cross	Affective/Behavioral/Cognitive
* Mårtensson et al. (2009)	189	57%	4–6 (5.3)	–	General	Sweden	Residential greenness/Proximity green space	Index	Attention Deficit Disorders Evaluation Scale (ADDES)	PR	Cross	Behavioral/Cognitive
McCracken et al. (2016)	287	44%	8–11 (9.5)	–	General	Scotland	Time spent in green areas/Residential greenness	SR/Index	Measure for Health Related Quality of Life (Kid-KINDL)	SR	Cross	Cross Affective
Readdick & Schaller (2005)	78	53%	6–12 (9.0)	100%	At-risk	USA	Summer camp	–	Piers-Harris Children's Self-concept Scale	SR	Pre-post	Affective
* Richardson, Pearce, Shortt, & Mitchell (2017)	5217	51%	4.85	–	General	Scotland	Residential greenness	Index	Strengths and Difficulties Questionnaire (SDQ)	PR	Long	Affective/Behavioral/Cognitive
Scott et al. (2018)	2876	55.4%	4–5 (4.4)	93.4%	At-risk	USA	Residential tree canopy/residential park access/residential greenness/school tree canopy/school park access/school greenness	Index	Devereux Early Childhood Assessment Preschool Program (DECA)	TR	Long	Behavioral/Affective

(continued on next page)

Table 1 (continued)

Author(s) (Year) <sup>b</sup>	N	Sex %boys	Age <sub>range</sub> in years (M <sub>age</sub> )	Eth.	Type sample	Country	Type nature/measure for nature	Informant/ Instrument nature	Instrument outcome	Informant outcome	Design	Self-regulation
Swank & Min Shin (2015)	33	84%	5–12 (8.1)	77%	At-risk	USA	Garden counseling	–	Piers-Harris Children's Self-concept Scale-2	SR	Pre-post	Affective
Van Aart et al. (2018)	172	50.9%	6.7–12.2	–	General	Belgium	Residential greenness	Index	Strengths and Difficulties Questionnaire (SDQ)/Questions on emotions	PR, SR	Long	Affective/ Behavioral/ Cognitive
Wells (2000)	17	53%	7–12 (9.5)	65%	At-risk	USA	Naturalness Scale	PR	Attention Deficit Disorders Evaluation Scale (ADDES)	PR	Pre-post	Cognitive
* Wells & Evans (2003)	337	51%	9–12 (9.2)	3%	General	USA	Naturalness Scale	PR	Global Self-Worth subscale (GSW)	SR	Cross	Cognitive
Whittington, Aspelmeier, & Budbill (2016)	87	0%	10–15 (11.6)	–	At-risk	USA	Outdoor Adventure Program	–	Resiliency Scale for Children and Adolescents (RSCA)	SR	Pre-post	Affective
* Yildirim & Akamca (2017)	35	46%	4.8–5.5	–	At risk	Turkey	Outdoor learning	–	Observation form	Obs	Pre-post	Cognitive/ Behavioral
* Zach et al. (2016)	5117	48.1%	5–7	7.8%	General	Germany	Accessibility of green spaces	PR	Strengths and Difficulties Questionnaire (SDQ)	PR	Cross	Affective/ Behavioral/ Cognitive

Note. N = number of participants; M<sub>age</sub> = Mean age; Ethn. %min = Ethnicity % minorities in sample (non-Caucasian); UK = United Kingdom; USA = United States of America; Greenness Index = Index for greenness of area (e.g., Normalized Difference Vegetation Index (NDVI)); Proximity = distance of home to nearest green space; Naturalness Scale = amount of nature from the window view, number of live plants indoors, material of the outdoor yard; SR = children's self-report; PR = parent-report.

SDQ = Strengths and Difficulties Questionnaire (Goodman, 1997); PANAS-C = Positive and Negative Affect Scale for Children (Watson, Clark, & Tellegen, 1988); ANT = Attentional Network Test to measure attention (Rueda, 2004); n-back test = a test for working memory/attention (Jaeggi, Buschkuhl, Perrig, & Meier, 2010); Delay of Gratification task = measure for self-regulation (Rodriguez, Mischel, & Shoda, 1989); Digit Span Backwards = measure for attention (Wechsler, 1955); STROOP Color-Word test = measure for attention (Dyer, 1973); PedsQL = Pediatric Quality of Life Inventory, measure for physical, psychological, and social functioning (Varni, Burwinkle, Seid, & Skarr, 2003); ADDES = (Early Childhood) Attention Deficit Disorders Evaluation Scale (McCarney, 1995); Kid-KINDL = measure for Health Related Quality of Life (physical, emotional, and social well-being; Ravens-Sieberer & Bullinger, 1998); PHCSCS(-2) = Piers-Harris Children's Self-concept Scale (2nd ed.) (Piers & Herzberg, 2002); DOG = Delay of Gratification; DSB = Digit Span Backwards; RSCA = Resiliency Scale for Children and Adolescents (Prince-Embury, 2007); GSW = The Global Self-Worth subscale of the Harter Competency Scale (Harter, 1982); Devereux Early Childhood Assessment Preschool Program (DECA) = self-regulation and behavioral concern (LeBuffe & Naglieri, 1999); K-CPT = task for attention (Conners & Staff, 2001); Behavioral Assessment System for Children (BASC-2, Reynolds, Kamphaus, & Vannest, 2011); Wellbeing check cards = part of the North West PCT evaluation kit (North West Primary Care Trust, 2012). ICD-10-GM = International Classification of Diseases (Deutsches Institut für Medizinische Dokumentation und Information, 2003). PR = parent reported; SR = child self-reported; TR = teacher reported; C = Clinical practitioner (e.g., psychologist or psychiatrist) Cross = cross-sectional design; Long = longitudinal design; Pre-post = pre-post test design.

\*These studies did not report the information needed to calculate effect sizes for the meta-analyses and were therefore excluded from analyses.

<sup>a</sup> We only included data on subsamples within the age-range of our inclusion criteria (4–12 years).

<sup>b</sup> Full references can be found in Appendix C Ref.

**Table 2**  
Study Characteristics of Included (Quasi-) Experimental Studies.

Author(s) (Year) <sup>a</sup>	N	n int.	n cont.	Sex (%) boys	Age range in years (M <sub>age</sub> )	Ethn.	Type sample	Country	Type control	Type nature	Duration	Exercise (y/n)	Random (y/n)	Instrument outcome	Informant outcome	Design	Self-regulation
Amicone et al., (2018)	82	82	82	52.4%	(10.1)	–	General	Italy	NI	School recess in green areas	–	Yes	No	The Bells test; Digit span; Go/No go test	Task	Cross-over	Cognitive
Bang, Kim, Song, Kang & Jeong (2018)	59	27	32	42%	(11.78)	–	At risk	Korea	NI	Forest Therapy	10 weeks	Yes	No	Rosenberg Self-esteem Scale (RSES) + Conners-Wells Adolescent Self-Report Scales	SR	CT	Affective/Cognitive
Barton, Sandercrock, Pretty & Wood (2015)	52	52	52	50%	–(8.84)	–	At-risk	UK	Playground sports (NGE)	Nature based playtime intervention (GE)	55 min	Yes	No	Rosenberg Self-esteem Scale (RSES)	SR	Cross-over	Affective
Duncan et al. (2014)	14	14	14	50%	9-10 (9.43)	33%	General	UK	Cycle	Cycling whilst watching a nature video (GE)	15 min	Yes	No	Brunel Mood State Inventory (BRUMS)	SR	Cross-over	Affective
Faber-Taylor & Kuo (2009)	25	25	25	88%	7-12 (9.2)	–	Clinical	USA	Walk	Exercise in a park (GE)	20 min	Yes	No	Symbol Digit Modalities	Task	Cross-over	Cognitive
Gustafsson, Szczepanski, Nelson, & Gustafsson (2012)	230	121	109	54%	6-11 (8.4)	31%	General	Sweden	NI	Outdoor Adventure Education	6 months	No	No	Strengths and Difficulties Questionnaire	PR	CT	Affective/Behavioral
Jenkin et al. (2018)	79	26	26	49%	8-11 (9.5)	–	General	UK	Urban video/Control video	Nature video	3 min	No	Yes	Symbol Digit Modalities; STROOP color-Word, Delay of gratification + Cantril's ladder	Task	RCT	Cognitive/Affective
* Largo-Wight et al., (2018)	36	36	36	56%	5-6	11%	General	USA	Indoor classroom	Outdoor classroom	6 weeks	No	No	The modified Face Scale	SR	Cross-over	Affective
Marcuso, Rizzitelli, & Azzarello (2006)	40	20	20	–	8-10 (9.0)	–	General	Italy	NI	Doing a task in the school garden	10 min	No	No	Trail making test	Task	CT	Cognitive
Mygind (2009)	19	19	19	26%	8-10 (9.1)	–	General	Denmark	NI	School lessons in forest setting (OE)	3 years	No	No	Self-developed instrument for (personal) and social development	SR	Cross-over	Affective/Behavioral
* Mygind, Stevenson, Liebst, Konvalinka, & Benisen (2018)	62	62	62	59.7	10-12 (10.9)	–	General	Denmark	NI	Education in natural setting	2 days	No	No	D2 test	Task	Cross-over	Cognitive
* Raney et al. (2019)	437	355	82	–	–	–	General	USA	NI	Schoolyard greening	4-5 months	Yes	No	Observing Play and Leisure Activity in Youth (SOPLAY)	Obs	CT	Behavioral
Reed et al. (2013)	86	86	86	–	11-12 (11.4)	–	General	UK	NGE	Exercise in a park (GE)	15 min	Yes	No	Rosenberg Self-esteem Scale (RSES)	SR	Cross-over	Affective
* Roe & Aspinall (2011)	18	18	18	83%	–(11)	–	General	UK	NI	School lessons in forest setting (OE)	1 day	No	No	Mood Adjective Checklist (MACL)	SR	Cross-over	Affective

(continued on next page)



Table 2 (continued)

Author(s) (Year) <sup>a</sup>	N	n int.	n cont.	Sex (% boys)	Age range in years (M <sub>age</sub> )	Ethn.	Type sample	Country	Type control	Type nature	Duration	Exercise (y/n)	Random (y/n)	Instrument outcome	Informant outcome	Design	Self-regulation
Schutte et al. (2017)	67	34	33	42%	4-8 (6.48)	7%	General	USA	UW	Park Walk (GE)	20 min	Yes	Yes	Trail making test; Go/noGo task	Task	RCT	Cognitive
Scrutton (2015)	475	360	115	50%	10-12 (11)	–	General	UK	NI	Outdoor Adventure Education	1 week	No	No	Self-developed instrument for personal and social development	SR	CT	Affective
Van den Berg et al. (2017)	170	84	86	57%	7-10 (9.00)	–	General	The Netherlands	NI	Green wall in the classroom	2 months	No	No	Self-developed instrument for (personal) and social development + Global Self-Worth subscale (GSW) + Smiley test; Digit Letter Substitution Test; Sky Search task; a five-item self-report measure of ability to concentrate	SR + Task	CT	Affective/Cognitive/Behavioral
Van Dijk-Wesselius et al. (2018)	706	351	355	49.7%	7-11 (8.6)	–	General	The Netherlands	NI	Schoolyard greening	3 years	Yes	No	Digit Letter Substitution Test; Sky Search task; Strengths and Difficulties Questionnaire (subscales); Subscale Interpersonal Relations of the Behavior Assessment System for Children (BASC-IR)	SR + Task	CT	Affective/Cognitive/Behavioral
* Walicze, Bradley, & Zajicek (2001)	538	–	–	43%	8-15(-)	–	General	USA	NI	Gardening	1 year	No	No	Subscale Interpersonal Relations of the Behavior Assessment System for Children (BASC-IR)	SR	CT	Behavioral
Wood, Gladwell, & Barton (2014)	25	25	25	48%	8-9 (8.6)	–	General	UK	NI	Exercise in the great outdoors (GE)	45 min	No	No	Rosenberg Self-esteem Scale (RSES)	SR	Cross-over	Affective

Note. N = number of participants; N<sub>interv</sub> = N intervention group; N<sub>cont</sub> = N control group; M<sub>age</sub> = Mean age; Ethn. %min = Ethnicity % minorities in sample (non-Caucasian); UK = United Kingdom; USA = United States of America.

OE = Outdoor Education; OAE = Outdoor Adventure Education; GE = Green Exercise; NI = No Intervention; NGE = Non-green Exercise; Random = Randomly assigned to intervention/comparison groups. SDQ = Strengths and Difficulties Questionnaire (Goodman, 1997); BRUMS = Brunel Mood State Inventory (Terry & Lane, 2003); RSES = Rosenberg Self-esteem Scale (Rosenberg, 1965); BASC = Behavior Assessment System for Children, subscale Interpersonal Relations (Reynolds et al., 2011); MACL = Mood Adjective Checklist (Mathews, Jones, & Chamberlain, 1990); GSW = The Global Self-Worth subscale of the Harter Competency Scale (Harter, 1982); Cantril's ladder = measure for mood (Cantril, 1966); Smiley test = measure for mood (Van den Berg et al., 2017); Trail making test (Sanchez-Cubillo et al., 2009); Symbol Digit Modalities Test (SDMT; Smith, 2002); STROOP Color-Word Test (Dyer, 1973); Digit Span Backwards (DSB; Wechsler, 1955); VT = Vigilance task (Gordon, McClure, & Aylward, 1996); Delay of Gratification task (DOG; Rodriguez et al., 1989); Go/noGo task (Wiebe, Sheffield, & Espy, 2012); Digit Letter Substitution Test (DLST), the Sky Search Task (a subset of the Test of Everyday Attention for Children; TEA-Ch; Manly et al., 2001), a five-item self-report measure of ability to concentrate (Van den Berg et al., 2016); The Bells test = selective and sustained attention (Biancardi & Stoppa, 1997); Face scale = measure of wellbeing and quality of life (Eiser, 2000). Cross = cross-sectional design; CT = controlled study; RCT = randomized controlled study; SR = child self-reported; PR = parent reported; Obs = observation.

\*This study did not report the information needed to calculate effect sizes for the meta-analyses and was therefore excluded from analyses.

<sup>a</sup> Full references can be found in Appendix C.

formula of [Peterson and Brown \(2005\)](#) ( $n = 11$ ,  $\beta_0 = .144$  [.068; .221]) were different from non-transformed effect sizes ( $n = 49$ ,  $\beta_0 = .079$  [.029; .129]), which seemed to be the case ( $F(1, 59) = 4.585$ ,  $p = .036$ ). Further inspection of the data showed that this was caused by a single beta-coefficient. After exclusion of the outlier from this preliminary analysis no significant differences were found. This indicates that in general effect sizes based on non-bivariate coefficients were not significantly different from other effect sizes ( $F(1, 58) = 2.048$ ,  $p = .158$ ). All correlation coefficients were transformed to Fisher's  $Z$  correlations.

In the (quasi-)experimental meta-analysis, effect sizes were expressed in Cohen's  $d$  values. These values were directly retrieved from the articles or calculated using pre-post group means and standard deviations (control vs. experimental group). Positive  $d$  values indicated improvements in self-regulation (e.g., more positive mood, better attention, less externalizing behavior) after exposure to nature relative to participants that were not exposed to nature.

**Moderators.** We coded sample characteristics as possible moderators: type of sample (general, at-risk or clinical), the mean age of children (in years), the percentage of boys in the sample, and ethnicity (i.e., because most studies were European or American, this was coded as the percentage of non-Caucasian children in the sample). Because only three studies included a clinical sample, these were taken together with the at risk samples. All these variables were tested as moderators (see [Appendix D](#), Table D1 for an overview).

Further, we coded a number of study characteristics as possible moderators: total sample size, year of publication, study location, duration and design of the study, the types of instruments that were used to assess exposure to nature and self-regulation, and the type of nature exposure and self-regulation that was assessed ([Appendix D](#)). These characteristics were all used as moderators. Type of conceptualization and instrument may be important since different conceptualizations or informants may lead to different results (see [Feng & Astell-Burt, 2017b](#); [Reid, Kubzansky, Li, Shmool, & Clougherty, 2018](#)). For country we could only test differences between European and North-American countries (including Canada), because other geographical areas were underrepresented in the dataset (i.e., of the studies from other areas, i.e., two Australian studies, one Turkish and one Korean study, only two studies were included in the analyses). Study design was re-coded cross-sectional and longitudinal studies as no time-lagged design, and pre-post-test studies (without control group) as time-lagged designs. Type of nature exposure was recoded in two categories, in correlational studies in residential greenness vs. green-based activities and in (quasi-)experimental studies as passive vs. active exposure. Type of self-regulation was recoded in three subdomains: cognitive, affective, and behavioral self-regulation ([Zimmerman, 2000](#)).

For (quasi-)experimental studies we additionally coded whether participants were randomly assigned to groups, the size ( $n$ ) of intervention and comparison groups, duration of the nature intervention, the type of control group, and whether the intervention contained exercise (yes or no). The latter may be important since there are indications that engaging with nature may be strongest when active (e.g., running, hiking/walking, biking, see [Holt, Lombard, Best, Smiley-Smith, & Quinn, 2019](#)).

**Inter-coder reliability.** To assess inter-coder reliability approximately 20% of studies were independently coded by both the first authors (agreement for the calculated effect sizes was  $> 90\%$ ). Coding differences were discussed. For example, some studies provided both cross-sectional and longitudinal data, which led to differences in the number of coded effect sizes. Only two of the correlational studies ([Feng & Astell-Burt, 2017a](#); [Flouri et al., 2014](#)) and five of the (quasi-)experimental studies ([Gustafsson et al., 2012](#); [Mygind, 2009](#); [Raney et al., 2019](#); [Van den Berg, Wesselius, Maas, & Dijkstra, 2017](#); [Van Dijk-Wesselius, Maas, Hovinga, van Vugt, & Van den Berg, 2018](#)) reported longitudinal effects and the reported time-span significantly varied. After discussion, it was therefore decided to only include cross-sectional

effect sizes to optimize comparability of effects.

## 2.4. Analyses

The two meta-analyses were performed in R (version 3.5.0) using the metaphor package ([Assink & Wibbelink, 2016](#); [Viechtbauer, 2010](#)). All parameters of the three-level random effects models were estimated using the restricted maximum likelihood estimation, and the [Knapp and Hartung \(2003\)](#) method was used for calculating regression coefficients and confidence intervals ([Assink & Wibbelink, 2016](#)).

We used three-level meta-analytic modeling, which is a rather new and innovative method to deal with interdependency of included effect sizes. This way, all relevant effect sizes reported in primary studies can be included ([Assink & Wibbelink, 2016](#)). Three sources of variance are modeled in this approach: (1) sampling variance in effect size (i.e., over measures; level 1, using the formula of [Cheung, 2014](#)); (2) variance in effect sizes within studies (level 2); and (3) and variance in effect sizes between studies (level 3). One-sided log-likelihood-ratio-tests were used to assess level-2 or level-3 variance (see instructions by [Assink & Wibbelink, 2016](#)). Significant variance on level 2 or 3 indicate a heterogeneous effect size distribution. This means the effect sizes cannot be treated as one common effect size. In this case and/or when less than 75% of the total amount of variance can be attributed to sampling (level 1) variance ([Hunter & Schmidt, 1990](#)), we continued with moderator analyses.

## 3. Results

In the final analyses, a total of  $N = 31$  studies, with 21,443 children and/or parents were included. Children were on average 7.84 years old ( $SD = 2.46$ ) and about half of them were boys (50.5%). Most studies examined participants with a mean age between 8 and 12 years (87%). Over half of the studies reported significant positive associations between nature and self-regulation. Two studies reported a significant negative association between nature and self-regulation ([Raney et al., 2019](#); [Scott, Kilmer, Wang, Cook, & Haber, 2018](#)) (see [Appendix D](#) for graphical displays of estimated results, including confidence intervals of the effect size).

## 4. Meta-analysis correlational studies

To determine the overall association between exposure to nature and self-regulation, a meta-analysis based on correlational studies was performed. A total of 15 independent studies and samples were included, with 61 effect sizes, and a total sample of  $N = 18,873$ . See [Fig. 2](#) for the distribution of effect sizes. Thirty-two effect sizes were in the hypothesized direction: more exposure to nature was associated with better self-regulation. A significant small, positive general association ( $r = .099$ ;  $SE = .021$ ; 95%  $CI = [.056 \text{ } .141]$ ) was found between exposure to nature and self-regulation ( $t(60) = 4.650$ ,  $p < .001$ , see [Table 3](#)).

Possible publication bias was checked via inspection of a funnel plot. Deviation from a funnel-shaped distribution can indicate publication bias. Inspection of the figure ([Figure E1, Appendix E](#)) indicated asymmetry in the distribution of effect sizes (depicted by the black dots in the figure). Therefore, we continued with the trim-and-fill procedure ([Duval & Tweedie, 2000](#)). This procedure 'trims' (removes) small studies causing asymmetry and replaces each removed study with possibly missing studies until symmetry is restored (filling). This procedure resulted in fifteen possibly missing effect sizes on the left side of the funnel plot (depicted by the white dots in the figure). Therefore, we re-estimated the overall effect after these "missing" effect sizes were added to the dataset. The initially estimated overall effect ( $r = .099$ ) was larger than the "corrected" overall effect ( $r = .034$ ,  $\Delta r = .065$ ), indicating the presence of (a form of) bias that possibly leads to an overestimation of the association between nature and self-regulation.

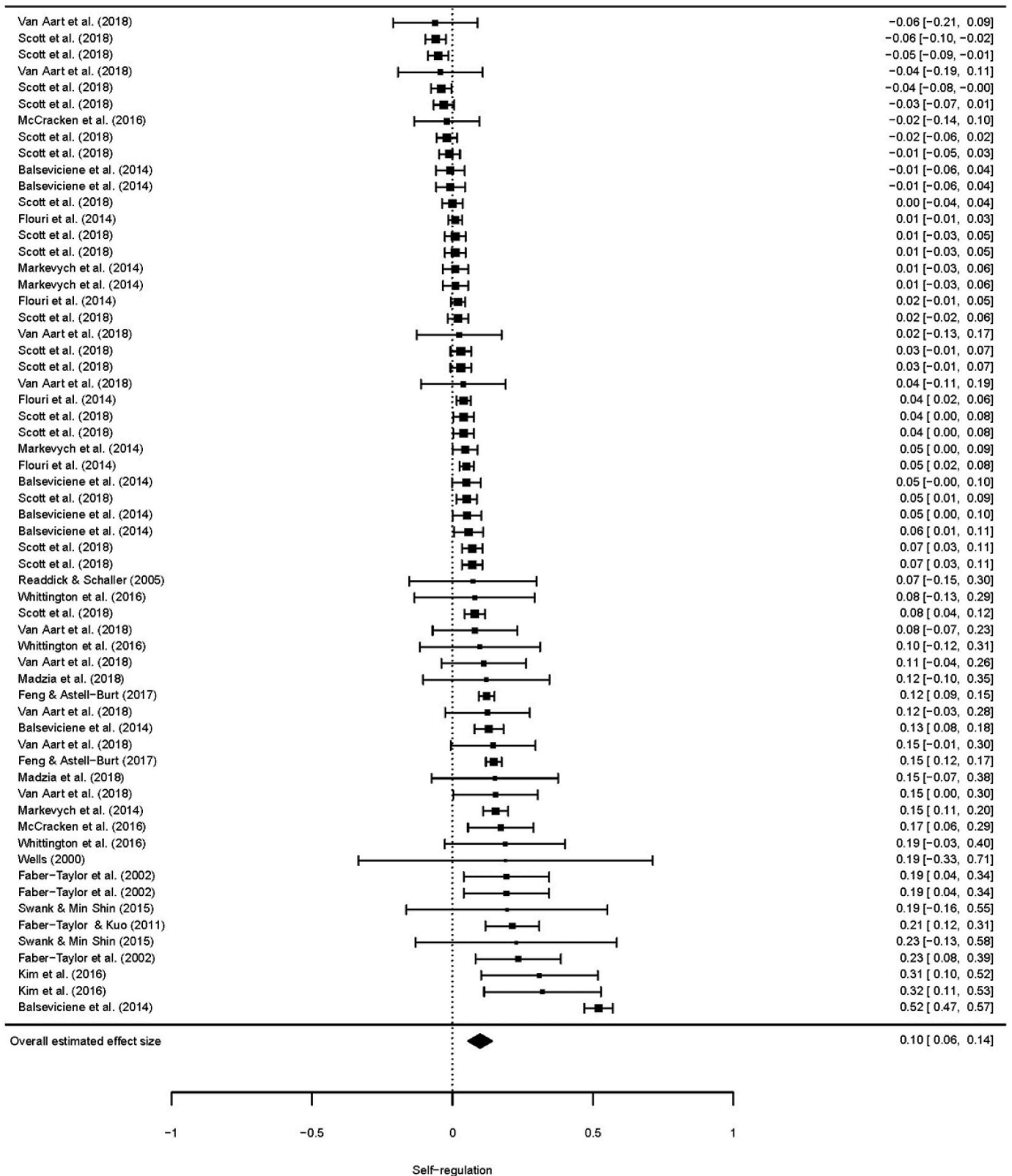


Fig. 2. Forest Plot Effect sizes Correlational Studies, including 95% confidence interval effect size.

Note. Forest plots were originally developed to show one effect size per study. Some studies are therefore mentioned more than once, to show multiple effect sizes from the same study.

Likelihood ratio tests were performed to determine the significance of the within (level 2) and between study (level 3) variance. We found significant variability in effect sizes that were extracted from the same studies (level 2 or within-study variance), as well as significant

variability in effect sizes between studies (level 3 or between-study variance). This heterogeneity in effect sizes may be explained by sample and study characteristics, and therefore, we continued with moderator analyses.

**Table 3**

Results of the meta-analyses of correlational and (Quasi-)Experimental studies: Overall effects and effect size heterogeneity.

Type of studies	<i>k</i>	#ES	Mean <i>r</i> / <i>d</i>	95% CI	<i>p</i>	<i>t</i>	σ <sup>2</sup> level 2	σ <sup>2</sup> level 3	% Var. level 1	% Var. level 2	% Var. level 3
Correlational studies	15	61	.099 ( <i>r</i> )	.056; .141	< .001	4.650	.006	.003	5.9%	66.3%	27.8%
(Quasi-)experimental studies	16	45	.151 ( <i>d</i> )	.079; .244	< .001	4.206	.025	.000	45.8%	54.2%	< 0.1%

Note. *k* = number of independent studies; #ES = number of effect sizes; CI = confidence interval; mean *r* = mean effect size (Pearson's *r*); mean *d* = mean effect size (Cohen's *d*); σ<sup>2</sup>level 2 = variance between effect sizes within the same study; σ<sup>2</sup>level 3 = variance between studies; % Var. = percentage of variance explained.

**Table 4**

Results of (bivariate) moderation analyses in correlational studies.

Moderator variables	<i>k</i>	#ES	β <sub>0</sub> (mean <i>r</i> / <i>d</i> ) [CI]	<i>t</i> <sub>0</sub>	β <sub>1</sub> [CI]	<i>t</i> <sub>1</sub>	<i>F</i> (df <sub>1</sub> , df <sub>2</sub> )
<i>Type of self-regulation</i>	15	61					<i>F</i> (2,58) = .840
Affective (RC)	12	26	0.099 [.048; .150]	3.901***			
Cognitive	3	3	.178 [.037; .319]	2.534*	.079 [-.067; .225]	1.086	
Behavioral	10	32	.088 [.039; .136]	3.638***	−0.012 [-.064; .040]	−.447	
<i>Type of nature</i>	15	61					<i>F</i> (1,59) = 2.029
Greenness of area (RC)	11	53	.085 [.041; .129]	3.861***			
Green exercise	5	8	.163 [.061; .265]	3.211**	.078[-.032; .188]	1.424	
<i>Sample characteristics</i>							
Age	14	60	.025 [-.096; .146]	.417	.009 [-.006; .025]	1.182	<i>F</i> (1,58) = 1.398
% boys in sample	14	59	.095 [-.065; .255]	1.192	.000 [-.003; .003]	.049	<i>F</i> (1,57) = .002
% ethnic minorities in sample	9	42	.100 [-.043; .244]	1.410	.000 [-.002; .002]	.264	<i>F</i> (1,40) = .070
Type of sample	15	61					<i>F</i> (1,59) = 1.494
General (RC)	6	28	.077 [.017; .138]	2.551*			
At-risk or clinical	9	33	.134 [.064; .203]	3.861***	.056 [-.036; .149]	1.222	
<i>Study characteristics</i>							
Publication year	15	61	.209 [.074; .344]	3.094**	−.008[-.017; .001]	−1.818	<i>F</i> (1,59) = 3.307
Design	15	61					<i>F</i> (1,59) = .288
No time lag (RC)	11	54	.095 [.050; .140]	4.242***			
Time lag	7	7	.133 [-.003; .270]	1.956	.039 [-.105; .182]	.537	
Location	14	59					<i>F</i> (1,57) = 1.864
Europe (RC)	5	26	.068 [.001; .135]	2.043*			
North-America	9	33	.135 [.064; .205]	3.821***	.066[-.031; .164]	1.365	
<i>Type of instrument nature</i>	12	54					<i>F</i> (1,52) = 7.632**
Index (RC)	9	48	.065 [.026 .104]	3.367**			
Parent-report	4	6	.221[.114; .327]	4.163***	.156 [.043; .269]	2.763**	
<i>Type of instrument outcome (self-regulation)</i>	13	40					<i>F</i> (1,38) = 1.858
Parent-report (RC)	7	24	.079 [.033; .125]	3.502**			
Self-report	7	16	.137[.065; .209]	3.837***	.058 [-.028; .143]	1.363	

Note. *k* = number of independent samples; #ES = number of effect sizes; β<sub>0</sub> (mean *r*/*d*) = intercept/mean effect size (*r*/*d*); *t*<sub>0</sub> = *t*-test statistic of the difference between the mean *r* or *d* and zero; β<sub>1</sub> = estimated regression coefficient; *t*<sub>1</sub> = *t*-test statistic of the difference between a category's mean *r* or *d* and the mean *r* or *d* of the reference category; *F*(df<sub>1</sub>, df<sub>2</sub>) = omnibus test; (RC) = reference category, CI = confidence interval.

\**p* < .05; \*\**p* < .01; \*\*\**p* < .001.

#### 4.1. Moderation analyses correlational studies

**Sample characteristics.** The type of sample, gender and ethnicity did not moderate the association between exposure to nature and self-regulation. See Table 4 for results of the moderation analyses.

**Study characteristics.** For publication year, the type of study design, study location, no significant moderation was found. Also, the type of self-regulation and the type of nature exposure that was assessed did not significantly moderate the effect of nature. We did find a significant moderation effect for the type of instrument to measure exposure to nature (index vs. parent-report). Stronger associations were found in studies where exposure to nature was measured by parent-report (*r* = .156) than in studies using an index (*r* = .065, *F*(1, 52) = 7.632, *p* = .008).

### 5. Meta-analysis (quasi-)experimental studies

To determine the overall effect of exposure to nature on self-regulation, a meta-analysis based on (quasi-)experimental studies was performed. Sixteen independent studies were included, with seventeen independent samples, 45 effect sizes, and a total sample of *N* = 2,570 (*n* = 1,689 for experimental groups; *n* = 1,167 for comparison/control

groups). Fig. 3 shows the distribution of effect sizes. Ten effect sizes were in the hypothesized direction: exposure to nature lead to better self-regulation. A significant small, positive overall effect (*d* = .151; *SE* = .036; 95% *CI* = [.079 - .224]) was found, indicating that children's self-regulation was significantly higher in children that were exposed to nature, relative to children that were not exposed to nature (*t*(44) = 4.206, *p* < .001, see Table 5). The funnel plot (Figure E2, Appendix E) detected some asymmetry in the distribution of effect sizes of the (quasi-)experimental studies. However, the trim-and-fill procedure did not lead to inclusion of possibly missing studies to the funnel and thus indicated no bias (Duval & Tweedie, 2000). The results of the log-likelihood-ratio tests indicated significant level-2 variance, but no significant level-3 variance. In an attempt to further explain the level-2 (within-study) variance, we continued with moderator analyses.

#### 5.1. Moderation analyses for (quasi) experimental studies

The type of self-regulation and the type of instrument used to measure self-regulation did not moderate the association between exposure to nature and self-regulation. See Table 5 for results of the moderator analyses for the (quasi) experimental studies.



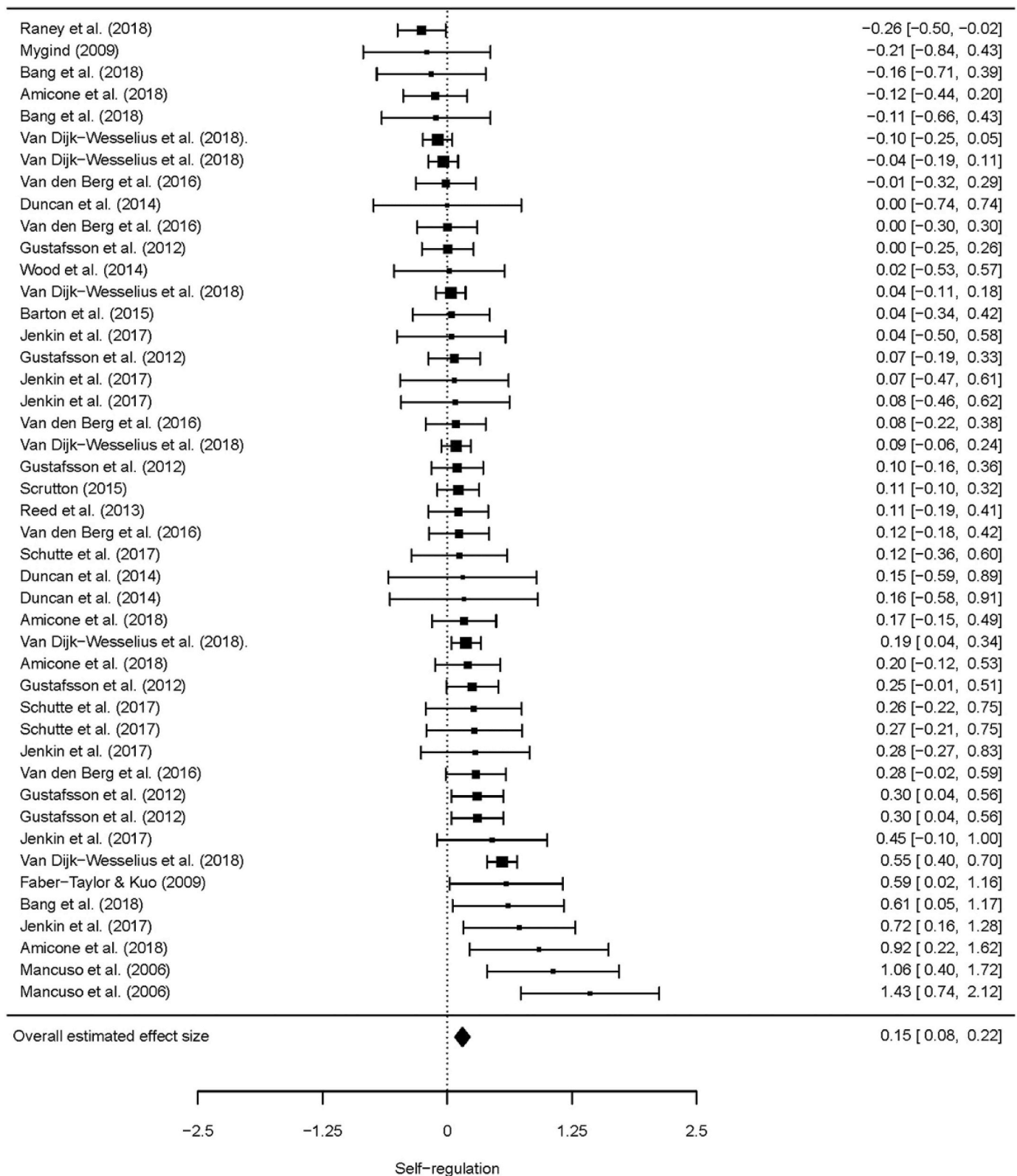


Fig. 3. Forest Plot Effect sizes Experimental Studies, including 95% confidence interval effect size.

Note. Forest plots were originally developed to show one effect size per study. Some studies are therefore mentioned more than once, to show multiple effect sizes from the same study.

## 6. Discussion

Studies on the beneficial effects of “a dose of nature” on our mental health is a rapidly growing literature. In schoolchildren, exposure to

nature might have positive effects on important developmental challenges, specifically learning how to exert self-control. However, to date there is no clear overview of the evidence. The aim of this study was to create a meta-analytic overview of studies assessing the effects of

**Table 5**  
Results of (Bivariate) Moderator Analyses in Experimental studies.

Moderators (quasi) experimental studies							
Type of self-regulation	17	45					$F(2, 42) = .406$
Affective (RC)	11	14	.174 [.031; .317]	2.452*			
Cognitive	10	17	.186 [.055; .316]	2.862**	.011 [-.183; .205]	.118	
Behavioral	8	14	.111 [-.013; .235]	1.807	-.063 [-.253; .126]	-.675	
Type of nature intervention	17	45					$F(1, 43) = 0.358$
Passive (RC)	9	26	.139 [.055; .223]	3.327**			
Active	8	19	.206 [.104; .308]	4.070***	.050 [-.118; .217]	.598	
Type of instrument outcome (self-regulation)	17	45					$F(1, 43) = .145$
Other (e.g., task) (RC)	10	24	.141 [.044; .238]	2.944**			
Questionnaire	10	21	.170 [.053; .287]	2.930**	.029 [-.123; .180]	.380	

Note.  $k$  = number of independent samples;  $\#ES$  = number of effect sizes;  $\beta_0$  (mean  $r/d$ ) = intercept/mean effect size ( $r/d$ );  $t_0$  =  $t$ -test statistic of the difference between the mean  $r$  or  $d$  and zero;  $\beta_1$  = estimated regression coefficient;  $t_1$  =  $t$ -test statistic of the difference between a category's mean  $r$  or  $d$  and the mean  $r$  or  $d$  of the reference category;  $F(df_1, df_2)$  = omnibus test; (RC) = reference category, CI = confidence interval.

\* $p < .05$ ; \*\* $p < .01$ ; \*\*\* $p < .001$ .

nature on cognitive, affective, and behavioral self-regulation of schoolchildren aged 4–12 years. Our literature search yielded 49 studies on exposure to nature and self-regulation, of which 31 could be included in the analyses. We conducted two separate three-level meta-analyses, one on 15 correlation studies and one on 16 (quasi-)experimental studies.

Over half of the included studies showed significant positive effects of nature. Two studies reported a significant negative effect. Our meta-analysis on correlational studies shows that in general there is a small but significant positive association between nature and self-regulation ( $r = .10$ ). Children living in greener neighborhoods or who are more (frequently) exposed to nature show better self-regulation. Similarly, a small but significant positive effect of nature was found in (quasi-)experimental studies: When compared to children in control conditions, children exposed to nature show better self-regulation ( $d = .15$ ). Our findings thus support the hypothesis that a natural environment contains beneficial elements for child development (e.g., Kaplan, 1995; Kellert, 2005; Ulrich, 1981; Ulrich et al., 1991) and specifically positively impacts cognitive, affective, and behavioral self-regulation.

We explored possible moderators to explain the variance found in effect sizes within and between studies. We found no evidence for differential effects of nature based on sample characteristics, such as children's age, gender or ethnicity. Moreover, no differences were found based on population (i.e., at risk or general) or study location. This may indicate that exposure to nature is beneficial for all children within the age-range of this study. However, the comparison of effects based on study population and location was limited since most studies ( $n = 34$ ) use a general population sample. Among the correlational studies only eight used an at-risk sample and four a clinical sample (Chiumento et al., 2018; Faber-Taylor et al., 2011; Faber-Taylor & Kuo, 2001; Kuo & Taylor-Faber, 2004). Among the (quasi-)experimental studies two used an at-risk sample (Bang et al., 2018; Barton et al., 2015), and one a clinical sample (Faber-Taylor & Kuo, 2009). Also, we found only four studies that were performed outside Europe and the USA, namely two Australian studies, one Turkish and one Korean study, of which only two studies could be included in the analyses. To improve further specificity and generalizability of our results, as well as to gain more insight into possible differential effects of nature in different populations and regions, we need more studies in clinical samples and from other continents. Overall, our moderation analyses only explained little of the variance in effects of nature within and between studies. This indicated that other moderators may affect the effect of nature. For example, some factors now included as control variables in most studies, such as SES or urbanization, may be moderators. Indeed, parental education moderated the effects of living close to a park on children's emotional problems (Balseviciene et al., 2014).

Within and between correlational studies differential effects of nature were found based on the type of instrument used to measure

nature exposure. Stronger associations were found in studies where exposure to nature was measured via parent-reports ( $r = .16$ ) than via an index score (such as the Green Vegetation Index (GVI) or Normative Difference Vegetation Index (NDVI) ( $r = .07$ ). This might indicate that subjective experiences of nature are more important than the amount of vegetation or land use. If this hypothesis is true the quality rather than the quantity of nature might thus be important. Indeed in adults, rural and coastal green spaces, as well as designated nature areas such as national parks, have been shown to be experienced as more restorative than urban green space (Wyles et al., 2019). Alternatively, and specifically in studies in which parents are the informant on both nature exposure and its outcome, this may indicate a bias: a third factor may explain why parents report both poor self-regulation in their children and less exposure to nature. For example, parents who experience stress may evaluate their neighborhood, leisure activities, and children's behavior as more negatively than parents who experience less stress (e.g., Gobin, Banks, Fins, & Tartar, 2015).

Our meta-analyses have limitations which are important to discuss. First, our literature search yielded a small number of studies. Initially 49 studies (29 correlational and 20 (quasi-)experimental) were included and coded. This small number of studies further decreased, because studies did not report the necessary information to calculate effect sizes. Specifically, in 13 correlational studies standardized, univariate associations between nature and self-regulation measures were missing in the paper and were not/could not be provided by the authors upon request. In five experimental studies the (pre-post) group means, standard deviations and/or group sizes per experimental condition were missing in the paper and were not/could not be provided by the authors upon request. For these studies a standardized association or effect size could not be calculated. This resulted in 31 studies which were included in the analyses.

Second, sample sizes of the included studies vary and are often small. In correlational studies they varied between 17 (Wells, 2000) and 66,823 (Markevych et al., 2019) with a median sample size of 287. In (quasi-)experimental studies they varied between 14 (Duncan et al., 2014) and 706 (Van Dijk-Wesselius et al., 2018) with a median sample size of 75. Combined with the often small effect sizes, this leads to low statistical power. Third, only three of the included studies used a rigorous RCT design. Since other study designs can not completely rule out alternative explanations for the association between nature exposure and self-regulation, we are in need of more experimental evidence.

Fourth, although there were no indications for a publication bias in (quasi-)experimental studies, our estimated overall association between nature and self-regulation in correlational studies may be a slight overestimation. This possibly indicates a publication bias in which significant results are more likely to get published than non-significant findings. Finally, most studies did not report the needed information to assess possible bias in their results as was described in our initial

protocol, such as how participants were allocated to different conditions and whether allocation was concealed (for experimental studies) or selective reporting (based on Higgins et al., 2011, see also; Tillmann et al., 2018). This is important, because the quality of a meta-analysis depends on the quality of the included studies.

Some observations about the quality of the included studies can be made based on our overview of studies (see for guidelines Moola et al., 2017). When it comes to the description of the sample and the study setting, in many studies important information about the sample and procedures was missing. For example, in 31 (63%) of the coded studies, ethnicity was not reported and four studies did not report on sex (see Tables 3 and 4). This missing data also led to a decrease in studies which could be included in the moderation analyses. The type, as well as the validity and reliability, of measures used for nature exposure and outcomes differed largely between studies. Within the correlational studies alone, sixteen different types of exposure to nature were described, varying from an index score for residential greenness to outdoor learning. For example, nature exposure was measured through satellite data on children's residential area (e.g., Normalized Difference Vegetation Index (NDVI), see for example Dadvand et al., 2018), but also through parent-reported window views (Faber-Taylor et al., 2002). The validity of these instruments may be dependent on the specific research question. For example, self-described neighborhood quality may be a valid instrument for assessing subjective experiences of nature, whereas an index scores might be more valid for assessing vegetation levels (Reid, Clougherty, Shmool, & Kubzansky, 2017).

The quality of measures used to assess self-regulation also differed between studies. In some studies self-developed instruments were used for which validity is unknown (e.g., Faber-Taylor & Kuo, 2011; Mygind, 2009; Yildirim & Akamca, 2017). Moreover, assessing complex multidimensional constructs, such as ADHD, using one or few questions might be problematic in terms of validity (Faber-Taylor & Kuo, 2011). In other studies, informants were not blind to the goal of the study or the condition to which participants were allocated (e.g., behavioral observations by the involved researchers, Yildirim & Akamca, 2017). This increases the risk of an observer-expectancy effect (i.e., a bias based on the researcher's expectations).

The large differences in conceptualization and measures between studies may also lead to different results and complicate the comparison of studies and study outcomes (see Feng & Astell-Burt, 2017b; Reid et al., 2018). Specific hypotheses on which specific aspects of nature may benefit which specific aspects of self-regulation, and why, may inform our designs and measures, and eventually lead to more comparable studies and more conclusive evidence. For example, if we hypothesize that nature benefits children through their subjective experiences, self-reported measures on, for example, quality of nature, mood and wellbeing, might be most appropriate. However, if we hypothesize that spending time away from built environments affects our cognitive capacities or physiological stress system, measuring actual time spend in nature, and assessing our functioning with tasks or physiological stress measures may be better suited. This might however call for inter-disciplinary collaboration in studying the beneficial effects of nature.

Although the findings of this meta-analysis give us little insight in how exposure to nature may benefit children's self-regulatory capacities, the included studies may still inform our hypotheses (see Markevych et al., 2017). Several studies tested protective mechanisms. For example, both crowding and access to green spaces were related to parent-reported total emotional, cognitive and behavioral difficulties in their children (Zach et al., 2016). Also, the effect of residential greenness predicted children's self-reported positive emotions over time, which was partly explained by residential noise (Van Aart et al., 2018). Future research should test possible protective qualities of nature, such as trees being a buffer for noise and pollution and parks being a recreational area away from crowds.

Several studies also indicate that just looking at nature, such as via a window view or a video, has restorative effects (see Faber-Taylor et al., 2002; Jenkin et al., 2018). However, findings of Jenkin et al. (2018) indicate that this effect may be explained by the depleting effects of a built environment rather than the restorative effects of a natural environment. Such restorative mechanisms may be specifically related to the quality of the environment, specifically to eye-level panoramic views rather than the quantity such as general residential greenness. Moreover, built environments with a biophilic design could have similar restorative effects to outside natural environments (see Kellert, Heerwagen, & Mador, 2011, although this was not found in respect to historical sights, see Scopelliti, Carrus, & Bonaiuto, 2018). Future studies should also explore the role of biophilic qualities of our surroundings such as natural lighting and ventilation, natural materials, shapes, colors, and patterns, and open space.

When it comes to promotive mechanisms, studies have explored physical exercise as a mechanism. Children, specifically girls, show more physical activity in green schoolyards and playgrounds than in paved areas (Raney et al., 2019; Van Dijk-Wesselius et al., 2018). Physical activity may thus specifically underlie the effects of nature in girls, possibly because for girls paved areas are less inviting for physical activities, whereas boys more easily find physical activities in all areas, no matter the greenness (e.g., ballgames such as soccer). Future research should also test additional promotive mechanisms such as the role of exploration and play or social interactions. Such promotive mechanisms may be specifically related to access or distance to greenspace and actual use of green space, rather than to mere views of nature. Future studies could, for example, use intensive longitudinal data—such as diary data, activity tracking, and ecological momentary assessment strategies such as experience sampling methods—to gain more insights in these mechanisms. A complicating factor is these different mechanisms are interdependent and/or intertwined and should thus be assessed and tested simultaneously in order to adequately test their unique contribution to the effects of nature (see Dzhambov, Hartig, Markevych, Tilov, & Dimitrova, 2018).

Since only few studies use a longitudinal design, it may also be important to distinguish between the effects of continuous vs. acute exposure to nature. For example, daily exposure to nature (e.g., residential greenness or green schoolyards) may buffer the negative effects of environmental and social risk factors over time, explaining differences between individuals, whereas acute exposure to nature (e.g., visiting a national park or green exercise) may lead to restoration and short term within-person improvements of self-regulation capacities. Indeed, it was found that regular visits to nature were associated with overall wellbeing and a recent visit with current feelings of happiness (White, Pahl, Wheeler, Depledge, & Fleming, 2017).

Another important question may be whether we expect nature to have the same effect across the life-span (see also Stevenson, Dewhurst, Schilhab, & Bentsen, 2019). Although in this meta-analyses, we found no evidence for moderation by age within the age-range of primary schoolchildren, differential effects of nature across developmental periods have been previously found (e.g., Barton & Pretty, 2010; Bos, Van der Meulen, Wichers, & Jeronimus, 2016). Different mechanisms may be at work during different life stages. For example, for children nature may facilitate exploration and physical play, for adolescents it may facilitate hanging out with peers without social control (see Weeland, Laceulle, Nederhof, Overbeek, & Reijneveld, 2019), and for adults it may facilitate getting away from daily stressors and clearing the mind (although the latter group may visit green spaces less frequently, e.g., Bos et al., 2016; Kotlaja, Wright, & Fagan, 2018; Roe, Aspinall & Ward Thompson, 2017). Moreover, some children may in general be more susceptible to the effects of their environment than others. For example, children who are more sensitive to environmental stimuli such as sound and light may benefit more from a natural environment, low on these stimuli, than children who are less sensitive

(Pluess et al., 2018). Future research should explore this.

## 7. Conclusion

Our study is the first meta-analytic review on the beneficial effects of exposure to nature in children. Using state of the art three-level analyses we found that exposure to nature has a small but significant positive effect on schoolchildren's self-regulation. Self-regulation is an important predictor of mental health and wellbeing (e.g., Compas et al., 2017). Although the overall effects of nature are small, they may still be meaningful and relevant for public health and clinical practice. Meaningful, because in our growing urban population the time children spend outdoors has drastically declined (e.g., Clements, 2004). For example, only 14% of Dutch children play outdoors every day, compared to 69% in earlier generations (Kantar Public, 2018). Relevant, since the effects of nature found in this meta-analysis are comparable to widely implemented school based prevention programs for, for example, child depression and anxiety (e.g., Werner-Seidler, Perry, Calear, Newby, & Christensen, 2017) or behavioral interventions for preventing overweight and obesity in children (e.g., Peirson et al., 2015).

Exposure to nature may thus be a promising tool for stimulating

self-regulation and preventing child psychopathology. Moreover, nature may also have important advantages over other prevention and intervention efforts. First of all, it can be easily implemented in different domains of children's environment, such as in schools and school yards, sports clubs and residential areas. Second, exposure to nature is affordable, accessible and safe. Exposing children to nature might also have spill-over effects: through additional beneficial effects on children's physical health (e.g., exercise); by positively affecting the physical and mental health of their accompanying parents, caregivers and teachers (possibly indirectly affecting parenting behavior) (e.g., Razani et al., 2018); and by improving communication (Cameron-Faulkner, Melville, & Gattis, 2018) and social cohesion.

## Declarations of interest

None.

## Acknowledgements

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## Appendix A. Search syntax

The searches below yielded the following results; PsycINFO (1369 references), ERIC (1598 references), Web of Science (1080 references) and MEDLINE (1013 references). Search strategies were reported according to Appelbaum et al. (2018).

*PsycINFO (Ovid, 1806 to April 24th, 2019)*

1. (preschool age 2 5 yrs OR school age 6 12 yrs OR adolescence 13 17 yrs).ag. OR childhood development/OR child psychiatry/OR orthopsychiatry/OR child psychopathology/OR child psychology/OR child psychotherapy/OR adolescent development/OR adolescent psychiatry/OR adolescent psychopathology/OR adolescent psychology/OR adolescent psychotherapy/OR nursery school students/OR kindergarten students/OR preschool students/OR elementary school students/OR primary school students/OR middle school students/OR junior high school students/OR high school students/OR (toddler\* OR child\* OR kid OR kids OR prepubescen\* OR prepuberty\* OR teen\* OR young\* OR youth\* OR girl\* OR boy\* OR preadolesc\* OR adolesc\* OR preschool\* OR elementary school\* OR primary education OR primary school\* OR K-12\* OR K12 OR 1st-grade\* OR first-grade\* OR grade 1 OR grade one OR 2nd-grade\* OR second-grade\* OR grade 2 OR grade two OR 3rd-grade\* OR third-grade\* OR grade 3 OR grade three OR 4th-grade\* OR fourth-grade\* OR grade 4 OR grade four OR 5th-grade\* OR fifth-grade\* OR grade 5 OR grade five OR 6th-grade\* OR sixth-grade\* OR grade 6 OR grade six OR intermediate general OR secondary education OR secondary school\* OR 7th-grade\* OR seventh-grade\* OR grade 7 OR grade seven OR 8th-grade\* OR eight-grade\* OR grade 8 OR grade eight OR 9th-grade\* OR ninth-grade\* OR grade 9 OR grade nine OR 10th-grade\* OR tenth-grade\* OR grade 10 OR grade ten OR 11th-grade\* OR eleventh-grade\* OR grade 11 OR grade eleven OR 12th-grade\* OR twelfth-grade\* OR grade 12 OR grade twelve OR junior high\* OR highschool\*).ti,ab,id.
2. "nature (environment)"/OR wilderness experience/OR (ecotherapy OR benefi\* of nature OR effect\* of nature OR ((exerc\* OR physical activit\* OR walk\*) ADJ3 (green OR nature)) OR exposure to nature OR ((forest OR park) ADJ3 (natural OR nature OR outside OR outdoor\*)) OR garden\* OR ((green\* OR natural OR nature) ADJ3 environment\*) OR greenness OR (green ADJ2 setting\*) OR green space\* OR greenspace\* OR natural outdoor\* OR NDVI OR school garden\* OR time in nature OR time spent in nature OR wilderness OR with nature).ti,ab,id,tm.
3. acting out/OR adolescent psychopathology/OR aggressive behavior/OR antisocial behavior/OR antisocial personality disorder/OR attention/OR attention deficit disorder/OR attention deficit disorder with hyperactivity/OR attention span/OR behavior disorders/OR behavior problems/OR childhood development/OR child psychiatry/OR child psychopathology/OR cognitive control/OR conduct disorder/OR "delay of gratification"/OR emotional adjustment/OR emotional development/OR emotional regulation/OR emotional responses/OR emotional states/OR emotions/OR executive function/OR explosive disorder/OR externalization/OR impulse control disorders/OR impulsiveness/OR juvenile delinquency/OR oppositional defiant disorder/OR orthopsychiatry/OR prosocial behavior/OR psychopathology/OR psychosocial development/OR selective attention/OR self-regulation/OR self-control/OR "sharing (social behavior)"/OR social adjustment/OR social behavior/OR social skills/OR sustained attention/OR tantrums/OR well being/OR (acting out OR ADHD\* OR affect\* OR aggress\* OR antisocial OR attent\* OR behavi\* difficult\* OR behavio\* disorder\* OR ((child\* OR help\*) ADJ3 sharing) OR cognitive control OR conduct behavior OR conduct disorder\* OR ((defiant OR disruptive OR dysfunctional\* OR explosiv\* OR maladaptiv\* OR problem\*) ADJ3 (behavio\* OR disorder\*)) OR delay of gratification OR delinq\* OR emotion\* OR executive function\* OR external\* OR hyperactiv\* OR impulse control OR impulsiv\* OR misbehavior\* OR misconduct OR mood OR oppositional behavior\* OR overreactivity OR irritab\* OR inhibition OR affect OR attention OR orthopsychiatr\* OR prosocial OR psychopatholog\* OR psychosocial\* OR self control OR selfcontrol OR self-efficacy OR selfefficacy OR self-esteem OR selfesteem OR self-regulat\* OR selfregulat\* OR sharing behavio#r OR sharing with other\* OR social adjust\* OR social\* behav\* OR social development\* OR social skill\* OR stress reduct\* OR tantrum\* OR well being OR wellbeing).ti,ab,id,tm.
4. animal.po.
5. 1 AND 2 AND 3
6. 5 NOT 4



Key: ag = age group, / = subject heading, ti = title, ab = abstract, id = key concepts (other keywords added by PsycINFO indexers to supplement the subject headings), tm = tests & measures.

ERIC (Ovid, 1965 to April 2019)

1. (early childhood education OR preschool education OR elementary secondary education OR grade 1 OR grade 2 OR grade 3 OR grade 4 OR grade 5 OR grade 6 OR grade 7 OR grade 8 OR grade 9 OR grade 10 OR grade 11 OR grade 12 OR elementary education OR primary education OR intermediate grades OR middle schools OR junior high schools OR secondary education OR high schools).el. OR toddlers/OR young children/OR child development/OR child psychology/OR child behavior/OR children/OR preadolescents/OR youth/OR adolescent development/OR adolescents/OR early adolescents/OR nursery schools/OR kindergarten/OR early childhood education/OR preschool children/OR preschool education/OR elementary secondary education/OR grade 1/OR grade 2/OR grade 3/OR grade 4/OR grade 5/OR grade 6/OR grade 7/OR grade 8/OR grade 9/OR grade 10/OR grade 11/OR grade 12/OR elementary education/OR elementary schools/OR elementary school students/OR primary education/OR middle schools/OR middle school students/OR junior high schools/OR junior high school students/OR secondary education/OR secondary schools/OR secondary school students/OR high schools/OR high school students/OR (toddler\* OR child\* OR kid OR kids OR prepubescen\* OR prepuberty\* OR teen\* OR young\* OR youth\* OR girl\* OR boy\* OR preadolesc\* OR adolesc\* OR preschool\* OR elementary school\* OR primary education OR primary school\* OR K-12\* OR K12 OR 1st-grade\* OR first-grade\* OR grade 1 OR grade one OR 2nd-grade\* OR second-grade\* OR grade 2 OR grade two OR 3rd-grade\* OR third-grade\* OR grade 3 OR grade three OR 4th-grade\* OR fourth-grade\* OR grade 4 OR grade four OR 5th-grade\* OR fifth-grade\* OR grade 5 OR grade five OR 6th-grade\* OR sixth-grade\* OR grade 6 OR grade six OR intermediate general OR secondary education OR secondary school\* OR 7th-grade\* OR seventh-grade\* OR grade 7 OR grade seven OR 8th-grade\* OR eighth-grade\* OR grade 8 OR grade eight OR 9th-grade\* OR ninth-grade\* OR grade 9 OR grade nine OR 10th-grade\* OR tenth-grade\* OR grade 10 OR grade ten OR 11th-grade\* OR eleventh-grade\* OR grade 11 OR grade eleven OR 12th-grade\* OR twelfth-grade\* OR grade 12 OR grade twelve OR junior high\* OR highschool\*).ti,ab,id.
2. outdoor education/OR parks/OR gardening/OR (ecotherapy OR benefi\* of nature OR effect\* of nature OR ((exerc\* OR physical activit\* OR walk\*) ADJ3 (green OR nature)) OR exposure to nature OR ((forest OR park) ADJ3 (natural OR nature OR outside OR outdoor\*)) OR garden\* OR ((green\* OR natural OR nature) ADJ3 environment\*) OR greenness OR (green ADJ2 setting\*) OR green space\* OR greenspace\* OR natural outdoor\* OR NDVI OR school garden\* OR time in nature OR time spent in nature OR wilderness OR with nature).ti,ab,id.
3. aggression/OR affective behavior/OR antisocial behavior/OR attention/OR attention control/OR attention deficit disorders/OR attention deficit hyperactivity disorder/OR attention span/OR behavior change/OR behavior disorders/OR behavior problems/OR child development/OR "delay of gratification"/OR delinquency/OR emotional development/OR emotional response/OR emotional adjustment/OR executive function/OR hyperactivity/OR prosocial behavior/OR psychiatry/OR psychopathology/OR self control/OR sharing behavior/OR social adjustment/OR social behavior/OR social development/OR well being/OR (acting out OR ADHD\* OR affect\* OR aggress\* OR antisocial OR attent\* OR behavi\* difficult\* OR behavio\* disorder\* OR ((child\* OR help\*) ADJ3 sharing) OR cognitive control OR conduct behavior OR conduct disorder\* OR ((defiant OR disruptive OR dysfunctional\* OR explosiv\* OR maladaptiv\* OR problem\*) ADJ3 (behavio\* OR disorder\*)) OR delay of gratification OR delinq\* OR emotion\* OR executive function\* OR external\* OR hyperactiv\* OR impulse control OR impulsiv\* OR misbehavio\* OR misconduct OR mood OR oppositional behavior\* OR overreactivity OR irritab\* OR inhibition OR affect OR attention OR orthopsychiatr\* OR prosocial OR psychopatholog\* OR psychosocial\* OR self control OR selfcontrol OR self-efficacy OR selfefficacy OR self-esteem OR selfesteem OR self-regulat\* OR selfregulat\* OR sharing behavio#r OR sharing with other\* OR social adjust\* OR social\* behav\* OR social development\* OR social skill\* OR stress reduct\* OR tantrum\* OR well being OR wellbeing).ti,ab,id.
4. 1 AND 2 AND 3

Key: el = educational level, ti = title, ab = abstract, id = key concepts (other keywords added by ERIC indexers to supplement the subject headings)

Web of Science (Web of Science Core Collection, 1975 to April 2019)

1. TS=("toddler\*" OR "child\*" OR "kid" OR "kids" OR "prepubescen\*" OR "prepuberty\*" OR "teen\*" OR "girl\*" OR "boy\*" OR "preadolesc\*" OR "adolesc\*" OR "preschool\*" OR "elementary school\*" OR "primary education" OR "primary school\*" OR "K-12\*" OR "K12" OR "1st-grade\*" OR "first-grade\*" OR "grade 1" OR "grade one" OR "2nd-grade\*" OR "second-grade\*" OR "grade 2" OR "grade two" OR "3rd-grade\*" OR "third-grade\*" OR "grade 3" OR "grade three" OR "4th-grade\*" OR "fourth-grade\*" OR "grade 4" OR "grade four" OR "5th-grade\*" OR "fifth-grade\*" OR "grade 5" OR "grade five" OR "6th-grade\*" OR "sixth-grade\*" OR "grade 6" OR "grade six" OR "intermediate general" OR "secondary education" OR "secondary school\*" OR "7th-grade\*" OR "seventh-grade\*" OR "grade 7" OR "grade seven" OR "8th-grade\*" OR "eight-grade\*" OR "grade 8" OR "grade eight" OR "9th-grade\*" OR "ninth-grade\*" OR "grade 9" OR "grade nine" OR "10th-grade\*" OR "tenth-grade\*" OR "grade 10" OR "grade ten" OR "11th-grade\*" OR "eleventh-grade\*" OR "grade 11" OR "grade eleven" OR "12th-grade\*" OR "twelfth-grade\*" OR "grade 12" OR "grade twelve" OR "junior high\*" OR "highschool\*")
2. TS=("ecotherapy" OR "benefi\* of nature" OR "effect\* of nature" OR ("exerc\*" OR "physical activit\*" OR "walk\*") NEAR/2 ("green" OR "nature")) OR "exposure to nature" OR ("forest" OR "park") NEAR/2 ("natural" OR "nature" OR "outside" OR "outdoor\*")) OR "garden\*" OR ("green\*" OR "natural" OR "nature") NEAR/2 ("environment\*") OR "greenness" OR ("green" NEAR/1 "setting\*") OR "green space\*" OR "greenspace\*" OR "natural outdoor\*" OR "NDVI" OR "school garden\*" OR "time in nature" OR "time spent in nature" OR "wilderness" OR "with nature")
3. TS=("acting out" OR "ADHD\*" OR "affect\*" OR "aggress\*" OR "antisocial" OR "attenti\*" OR "behavi\* difficult\*" OR ("child\*" OR "help\*") NEAR/2 "sharing") OR "cognitive control" OR "conduct behavior" OR "conduct disorder\*" OR ((defiant OR "disruptive" OR "dysfunctional\*" OR "explosiv\*" OR "maladaptiv\*" OR "problem\*") NEAR/2 ("behavio\*" OR "disorder\*")) OR "delay of gratification" OR "delinq\*" OR "emotion\*" OR "executive function\*" OR "external\*" OR "hyperactiv\*" OR "impulsiv\*" OR "misbehavio\*" OR "misconduct" OR "mood" OR "oppositional behavior\*" OR "overreactivity" OR "irritab\*" OR "inhibition" OR "affect" OR "attention" OR "prosocial" OR "psychosocial\*" OR "self-efficacy" OR "selfefficacy" OR "self-esteem" OR "selfesteem" OR "self-regulat\*" OR "selfregulat\*" OR "sharing behavio#r" OR "sharing with other\*" OR "social

adjust\*" OR "social\* behav\*" OR "social development\*" OR "social skill\*" OR "tantrum\*" OR "well being" OR "wellbeing" OR "behavio\* disorder\*" OR "impulse control" OR "psychopatholog\*" OR "stress reduct\*")

4. 1 AND 2 AND 3

Key: TS = topic, which includes title, abstract, author keywords and Web of Science Keywords Plus.

MEDLINE (Ovid MEDLINE, including epub ahead of print, in-process & other non-indexed citations and Ovid MEDLINE Daily, 1946 to April 24th 2019)

1. child behavior/OR child development/OR child psychiatry/OR orthopsychiatry/OR child psychology/OR child/OR puberty/OR adolescent/OR adolescent behavior/OR adolescent development/OR adolescent psychiatry/OR adolescent psychology/OR child, preschool/OR (toddler\* OR child\* OR kid OR kids OR prepubescen\* OR prepuberty\* OR teen\* OR young\* OR youth\* OR girl\* OR boy\* OR preadolesc\* OR adolesc\* OR preschool\* OR elementary school\* OR primary education OR primary school\* OR K-12\* OR K12 OR 1st-grade\* OR first-grade\* OR grade 1 OR grade one OR 2nd-grade\* OR second-grade\* OR grade 2 OR grade two OR 3rd-grade\* OR third-grade\* OR grade 3 OR grade three OR 4th-grade\* OR fourth-grade\* OR grade 4 OR grade four OR 5th-grade\* OR fifth-grade\* OR grade 5 OR grade five OR 6th-grade\* OR sixth-grade\* OR grade 6 OR grade six OR intermediate general OR secondary education OR secondary school\* OR 7th-grade\* OR seventh-grade\* OR grade 7 OR grade seven OR 8th-grade\* OR eight-grade\* OR grade 8 OR grade eight OR 9th-grade\* OR ninth-grade\* OR grade 9 OR grade nine OR 10th-grade\* OR tenth-grade\* OR grade 10 OR grade ten OR 11th-grade\* OR eleventh-grade\* OR grade 11 OR grade eleven OR 12th-grade\* OR twelfth-grade\* OR grade 12 OR grade twelve OR junior high\* OR highschool\*).ti,ab,kf.
2. nature/OR gardening/OR forests/OR parks, recreational/OR wilderness/OR (ecotherapy OR benefi\* of nature OR effect\* of nature OR ((exerc\* OR physical activit\* OR walk\*) ADJ3 (green OR nature)) OR exposure to nature OR ((forest OR park) ADJ3 (natural OR nature OR outside OR outdoor\*)) OR garden\* OR ((green\* OR natural OR nature) ADJ3 environment\*) OR greenness OR (green ADJ2 setting\*) OR green space\* OR greenspace\* OR natural outdoor\* OR NDVI OR school garden\* OR time in nature OR time spent in nature OR wilderness OR with nature).ti,ab,kf.
3. acting out/OR antisocial personality disorder/OR attention/OR "attention deficit and disruptive behavior disorders"/OR attention deficit disorder with hyperactivity/OR problem behavior/OR child behavior disorders/OR child development/OR child psychiatry/OR child psychology/OR conduct disorder/OR delay discounting/OR "disruptive, impulse control, and conduct disorders"/OR emotional adjustment/OR emotions/OR executive function/OR impulsive behavior/OR juvenile delinquency/OR orthopsychiatry/OR psychopathology/OR self-control/OR social adjustment/OR social behavior/OR social skills/OR stress, psychological/OR (acting out OR ADHD\* OR affect\* OR aggress\* OR antisocial OR attent\* OR behavi\* difficult\* OR behavio\* disorder\* OR ((child\* OR help\*) ADJ3 sharing) OR cognitive control OR conduct behavior OR conduct disorder\* OR ((defiant OR disruptive OR dysfunctional\* OR explosiv\* OR maladaptiv\* OR problem\*) ADJ3 (behavio\* OR disorder\*)) OR delay of gratification OR delinq\* OR emotion\* OR executive function\* OR externali\* OR hyperactiv\* OR impulse control OR impulsiv\* OR misbehavio\* OR misconduct OR mood OR oppositional behavior\* OR overreactivity OR irritab\* OR inhibition OR affect OR attention OR orthopsychiatr\* OR prosocial OR psychopatholog\* OR psychosocial\* OR self control OR selfcontrol OR self-efficacy OR selfefficacy OR self-esteem OR selfesteem OR self-regulat\* OR selfregulat\* OR sharing behavio#r OR sharing with other\* OR social adjust\* OR social\* behav\* OR social development\* OR social skill\* OR stress reduct\* OR tantrum\* OR well being OR wellbeing).ti,ab,kf.
4. animal/
5. 1 AND 2 AND 3
6. 5 NOT 4

Key:/= medical subject heading (MeSH), ti = title, ab = abstract, kf = author supplied keywords.

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## Appendix D. Overview of Coded Moderators

Table D.1  
Overview of Moderators and Coding.

Variable	Coding	Recoding for moderation analyses
<b>Sample characteristics</b>		
Type of sample	General, at risk, or clinical	General vs. at risk
Mean age in years		
Sex	% boys	Boys vs. girls
Ethnicity	% minority	Minority vs. no minority
<b>Study characteristics</b>		
Sample size		
Length of study	Length of the study in days	
Study design	e.g., longitudinal, pre-post, randomized controlled trial	Correlational: no time-lagged design, vs. time-lagged designs Experimental: Randomized controlled experimental studies (RCT), controlled experimental studies (CT), cross-over studies
Instrument nature	Type of instrument used to assess nature exposure, e.g., index, parent-report	Index vs. parent-report
Instrument self-regulation	Type of instrument used to assess self-regulation, e.g., self-report, task	Correlational: Parent-report vs. self-report Experimental: Questionnaire vs. other
Study location	Country where the study was conducted, e.g., United States of America, The Netherlands, Spain	European vs. North-American countries
Year of publication		
Type of nature (intervention)	Conceptualization of nature exposure, e.g., neighborhood greenness, green exercise, outdoor education	Correlational: Residential greenness vs. green-based activities; Experimental: Passive vs. active
Type of self-regulation	Conceptualization of self-regulation, e.g., attention, well-being, conduct behavior	Cognitive, affective, behavioral

(continued on next page)

Table D.1 (continued)

	Variable	Coding	Recoding for moderation analyses
For (quasi-)experimental studies only	Randomization	Yes/No	
	Duration of the intervention	Time-span of exposure to nature	short vs. long
	Type of control group	Type of control group or alternative intervention, e.g., no intervention	
	Exercise	Yes/No	
	N of control and experimental group		

Appendix E. Funnel plots

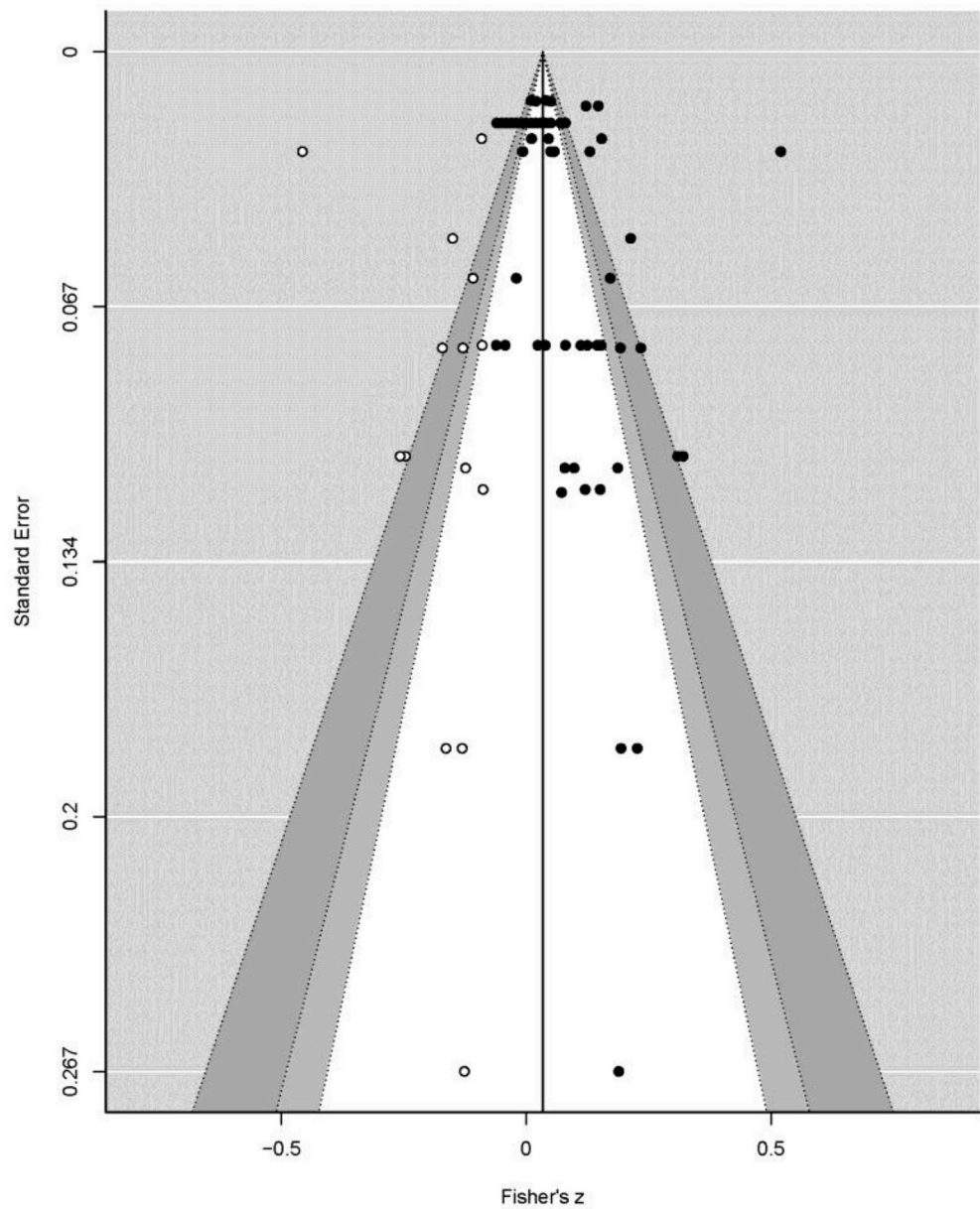


Fig. E.1. Funnel Plot Correlational Studies.  
Note. The black dots depict the effects sizes of the included studies, while the white dots depict the missing effect sizes identified by the trim and fill analysis.

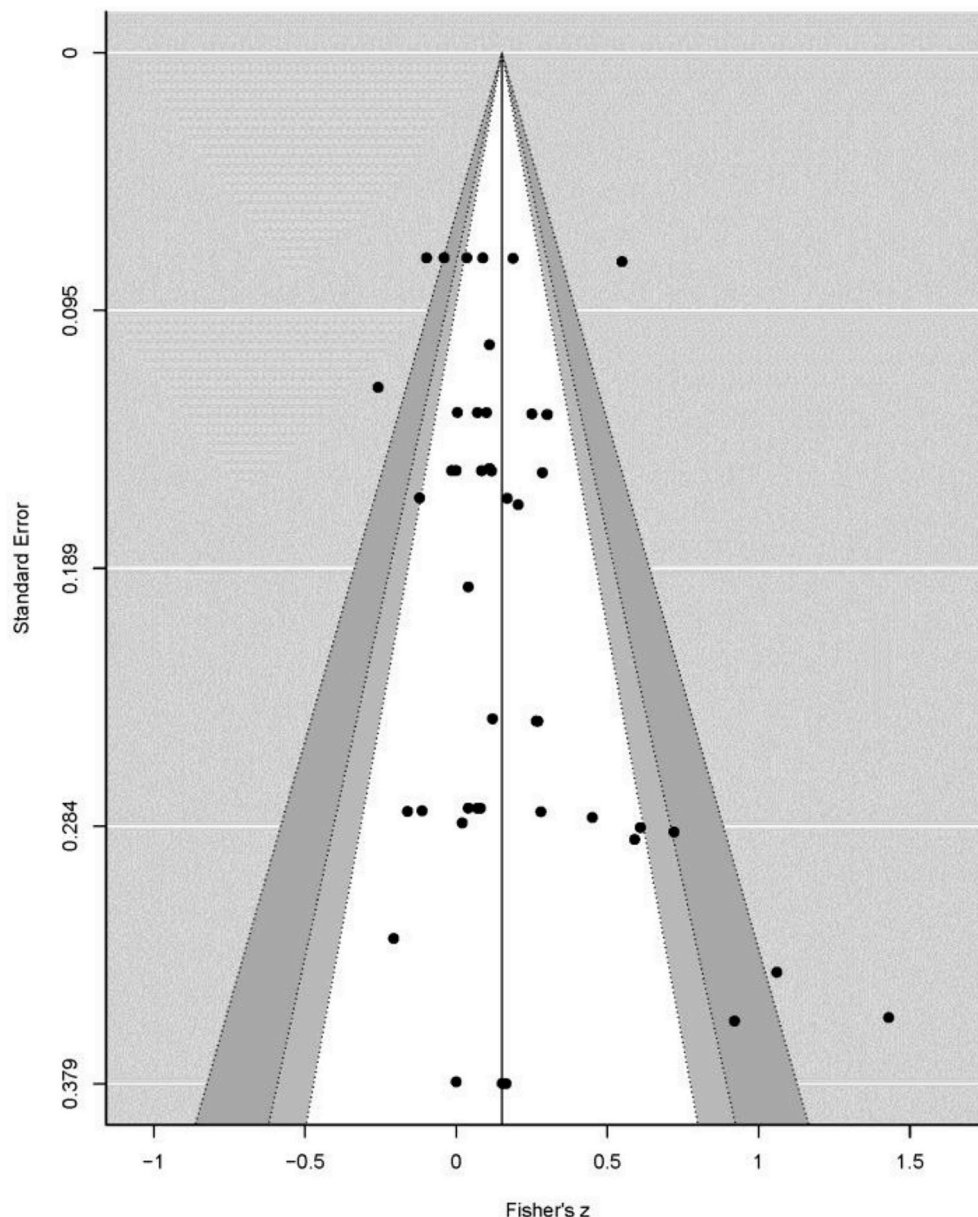


Fig. E.2. Funnel Plot (quasi-) Experimental Studies.

Note. The black dots depict the effects sizes of the included studies. No missing effect size were identified by the trim and fill analysis.

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